British Journal of Applied Science & Technology
6(5): 425-462, 2015, Article no.BJAST.2015.101
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

The Photon Concept and the Physics of Quantum Absorption Process

Dmitri Yerchuck*[1], Yauhen Yerchak[2], Alla Dovlatova[3], Vyacheslav Stelmakh[2] and Felix Borovik [1]

[1] *Heat-Mass Transfer Institute of National Academy of Sciences of RB, Brovka Str.15, Minsk, 220072, Belarus.*
[2] *Belarusian State University, Nezavisimosti Ave., 4, Minsk, 220030, Belarus.*
[3] *M.V.Lomonosov Moscow State University, Moscow, 119899, Russia.*

Article Information
DOI: 10.9734/BJAST/2015/12244
Editor(s):
(1) Mark Vimalan, Department of Physics, Syed Ammal Arts and Science College, India.
Reviewers:
(1) Anonymous, India.
(2) Antonio Santos, Instituto de Fsica, Federal University of Rio de Janeiro, Brazil.
(3) Anonymous, India.
(4) Anonymous, Malaysia.
(5) Rajendra Prasad Bajpai, Sophisticated Analytical Instrument Facility, North Eastern Hill University, India.
(6) Anonymous, Ireland.
Complete Peer review History:
http://www.sciencedomain.org/review-history.php?iid=768&id=5&aid=7529

Review Article

Received: 24 June 2014
Accepted: 03 November 2014
Published: 27 December 2014

Abstract

Aims/ objectives: The consideration of the three tasks, formulated below, is the aim of the given work.
The first task of the paper presented is to analyse the existing viewpoints and to give the conclusion on the real photon status.
To represent the clear and understandable explanation of the nature of the corpuscular-wave dualism and to give an insight into physics of the photon absorption process is the second task of the given review.

**Corresponding author: E-mail: dpy@tut.by*

The third task of the paper presented - to give the experimental proof for the Dirac theoretical conclusion, that the transitions of the quantum system from an equilibrium state to an excited state are not instantaneous and that a part of the time, related to a duration of the stay between the states can be determined.
Study design: The theory of quantum Fermi liquid, the developed Dirac quantisation method, the theory of quantum Rabi oscillations and experimental results of the stationary electron spin resonance (ESR) spectroscopy were used.
Place and Duration of Study: Heat-Mass Transfer Institute of National Academy of Sciences of RB, Belarusian State University and M.V.Lomonosov Moscow State University, between January 2014 and July 2014.
Methodology: We have used the quantum 1D Fermi liquid model for the description of 1D correlated electronic systems, elaborated in the application to the quantised electromagnetic (EM) field, the Jaynes-Cummings model (JCM) of quantum Rabi oscillations, new Slepyan-Yerchak-Hoffmann-Bass model of propagating quantum Rabi oscillations and new fully quantum space-time quantisation method.
Results: The status of the photon in the modern physics is analysed. In the physics of elementary particles the photon is considered to be the genuine elementary particle. The development of the viewpoint of the experts in the quantum electrodynamics theory is considered. It was established its change from the opinion, that the description of the photon to be the particle is impossible to the viewpoint on the photon to be the particle, that is, coinciding with the viewpoint, represented in the Standard Model of the physics of elementary particles.
The quantized Maxwellian EM-field represents itself, according to the new conceptual model reviewed, the sets of 1D rays, the own structure of each ray is discrete - 1D-lattice of spin-1 bosons. Therefore, the structure of EM-field in boson model resembles the structure of the carbon frame of organic polymers like to *trans*-polyacetylene in the matter. Photons in the given concept are the corpuscles, propagating along EM-field boson-"atomic" chains. In other words, EM-field boson-"atomic" chains represents themselves the medium for the photons' propagation. In the structural aspect photons in usual conditions are chargeless spin 1/2 topological relativistic solitons of Su-Schrieffer-Heeger family. Spinless charged solitons of the same family can also be formed in so-called "doped" EM-field structure.
The origin of waves in the EM-field boson-"atomic" structure is determined by the mechanism, being to be quite analogous to the formation of Bloch waves in the solid state of condensed matter. The expression for the corresponding wave function $\psi(\vec{r}, t)$ representing itself the set of Bloch-like waves is given. Just, the given function allows to describe correctly the wave properties of the light, including the interference. Corpuscular properties of EM-field including those ones by its interaction with matter are described by independent scalar field function $\Psi(\vec{r}, t)$, obtained from the solution of Schrödinger equation [nonstationary in general case] and usually called wave function. The term "wave" seems to be incorrect in application to the given function and has to be corrected in all literature on quantum theory, including textbooks.
The physics of quantum absorption process is analysed. It is argued, in accordance with Dirac guess, that the photon revival takes place by its absorption. It is concluded, that after the energy and impulse transfer to the absorbing system the photon state is a pinned state, in which it possesses the only by spin.
The reviewed rather unusual spectroscopic electron spin resonance absorption characteristics of carbon nanotubes and superconducting ceramics, obtained with the participation of the authors and of the other research groups and being earlier unexplained, were correctly interpreted within the frames of the phenomenological model of the spectroscopic transition dynamics with finite time of the transfer of absorbing systems in an excited state. Moreover, it was established, that the time of the transfer of absorbing systems in an excited state governs the characteristics of the stationary ESR signal registered in the carbon nanotubes and superconducting ceramics.
Conclusion: To describe correctly the EM-field properties including corpuscular-wave dualism [which is explained in a natural way] it is necessary to use the full variant of Schrödinger's theory, taking into consideration two scalar functions.
The result, that the time of the transfer of absorbing systems into an excited state governs the characteristics of the stationary ESR signal is significant for the stationary spectroscopy at all, since the transfer of absorbing systems in an excited state is considered in the stationary spectroscopy at present to be instantaneous.

Keywords: Quantized electromagnetic field; Photon status; Corpuscular-wave dualism; Spectroscopic transition dynamics

PACS, the Physics and Astronomy 42.50.Ct, 61.46.Fg, 73.22.f, 78.67.Ch, 77.90.+k, 76.50.+g

1 Introduction

The studies of optical properties of a number of condensed matter systems have shown, that there are phenomena, which can be explained the only within the frames of the concept of quantized electromagnetic field (EM-field) interacting with given systems, which have also to be described quantum-mechanically.

The basic quantisation paradigm itself was introduced in the physics by Planck [1]. The idea of the absorption or the emission of the energy of EM-field with material oscillators by discrete portions was in fact mathematically proved by Planck, although in the scientific literature is insisted that it was postulated [see for details the next Section]. At the same time Einstein [2, 3] was the first, who proposed to describe the EM-field to be quantised already in 1905, that is, in a long time before the creation of the foundations of quantum mechanics and quantum electrodynamics (QED) in 1925-1927. We wish to draw attention on the difference of Einstein idea from Planck idea. Planck idea [1] of the quantisation was consisting in that, that the absorbing atoms or molecules scoop the energy by the portions from the EM-field (light) medium without any indication, whether the light energy portions were formed beforehand, that is, whether they are the structural elements of the light, or the energy of the light is the continuos quantity. We wish to accentuate that the Einstein concept of light quanta to be the particles was the new paradigm, introduced in the physics for the first time basing on experimental results on the photoeffect mainly, that is, experimentally grounded [see for details the next Section]. In fact, it was the recovery of I.Newton concept on the corpuscular nature of the light on the new scientific level. Let us remark that the representation on the corpuscular nature of the light was considered by I.Newton the only on the intuitive level without any experimental grounds and we have to give his ingenious insight due.

Let us remember, that light quanta were called photons by Lewis in the spirit of I.Newton corpuscular concept slightly later, in 1926 [4].

At the same time, the experts in the the quantum electrodynamics theory have started from the opinion, that the photon cannot be considered being to be the relativistic particle in contrast to the viewpoint from the positions of the Standard Model of elementary particles. In fact, there was the discussion concerning the photon status between experts of different theoretical physics branches and in QED itself.

The first task of the paper presented is to analyse both the viewpoints and to give the conclusion on the real photon status.

The quantisation theory of EM-field from the positions of the foundations of quantum theory was proposed for the first time still at the earliest stage of the quantum physics era in the works [5, 6]. In given works quantum theory of dipole radiation was considered and the energy fluctuations in radiation field of blackbody have been calculated. The idea of EM-field quantisation, proposed by Born and Jordan in the work [5] consists in the representation of EM-field characteristic quantities by the matrices. In fact, it was the development in its mathematical description of the base Einstein concept, being formulated in [2, 3]. The Born-Jordan-Heisenberg idea [6], being to be mathematically correct, did not give at the same time any indications on the nature and on the character of the structure of EM-field, althogh it pointed out on its discreteness. In other words, from the physical viewpoint was nothing news in comparison with Einstein and even with Newton concepts, while mathematically the works [5, 6] are the foundations of QED.

The quite other idea - to set up in the correspondence to each mode of radiation field the quantized harmonic oscillator, was proposed for the first time by Dirac [7] and it is widely used in QED including quantum optics, it is the canonical quantisation. The given idea has the fundamental physical base. It allowed to unite the corpuscular and wave properties of the light, that is, to give start for the explanation of the quantum phenomenon of the corpuscular-wave dualism. At the same time, the concept itself of oscillating corpuscles was postulated, the origin of corpuscles and waves was not established, resulting in a rather vague explanation of the nature of the corpuscular-wave dualism.

To represent the clear and understandable explanation of the nature of the corpuscular-wave dualism and to give an insight into physics of the photon absorption process is the second task of the given review [see the third Section, where the explanation of the nature of the corpuscular-wave dualism on the concept of the boson model of EM-field is represented and the idea of the revival of photons by their absorption is proposed in contrast to the photon annihilation concept, existing at present].

The next aspect, which will be analysed in the paper presented is concerned of transitions of the quantum system from an equilibrium state to an excited state. The given process is considered in the modern spectroscopy to be an instantaneous. However, already Dirac in the work [8] has indicated, that the transitions of the quantum system from an equilibrium state to an excited state are not instantaneous and that a part of the time, related to a duration of the stay between the states can be determined theoretically. The given aspect determines the third task of the paper presented - to give the experimental proof for the Dirac theoretical conclusion. It was done taking into account the reviewed rather unusual spectroscopic magnetic resonance absorption characteristics of carbon nanotubes and superconducting ceramics, which were earlier unexplained [see the third Section]. The given results indicate on the necessity of the development of the quantum theory in the direction of the spectroscopic transitions with the finite time of transition processes from ground states into excited states.

The consideration of the three tasks above formulated in details is the aim of the given work.

2 Brief Comment to History of Experimental Results Leading to Quantum EM-Field Paradigm and to Necesssity of QED-Theory Development

Let us give a brief review of the history of the experimental confirmation of the necessity to consider the EM-field to be quantised. We accentuate once again, that A.Einstein was the first, who proposed to describe the EM-field to be quantised and he confirmed the given conclusion by the analysis of the experimental results on the photoeffect phenomenon [2, 3]. Let us remember, that the given phenomenon was discovered by Hertz in 1887, was studied by Stoletov (1888), Lenard and Tomson (1889), however, the only A.Einstein have explained the main regularities of the photoeffect in the suggestion, that the energy of EM-field has to be quantised, in 1905, that is, long before of the appearance of the first works on the theory of the EM-field quantisation [5, 6, 7]. Let us regard the reasons of A.Einstein proof in more details. There were explained the following main properties: 1) the independence of the maximal kinetic energy of photoelectrons on the light intensity, 2) the linear dependence of the maximal kinetic energy of photoelectrons on the light frequency and 3) the existence of the minimal light frequency (threshold frequency). Let us remark, that the linear dependence of the maximal kinetic energy of photoelectrons on the light frequency can be explained on the base of the ealier idea [1] of the quantisation of the energy of light absorbing atomic systems only. According to Planck the absorbing atomic systems can in principle scoop the energy by the portions from the continuosly or discretely distributed energy in EM-field medium. Planck does not discuss the given detail.

At the same time, the independence of the maximal kinetic energy of photoelectrons on the light intensity and the existence of the threshold light frequency could be explained the only on the base of the quantisation of the energy of the light, just that has been done by A.Einstein [2].

So, it was described above the standard role of the work [2], that is, considered to be the work delighted to the explanation of a photoeffect in the suggestion of a quantisation of the energy of EM-field [at that we draw attention on the difference of the quantisation process considered by Einstein in comparison with the quantisation process considered by Planck].

However, in reality, the scientific significance of the given work is lot more. Along with a photoeffect a blackbody radiation and a photoluminiscece were considered. Einstein writes: "Es scheint mir nun in der Tat, dass die Beobachtungen über die "schwarze Strahlung", Photolumineszenz, die Erzeugung von Kathodenstrahlen durch ultraviolettes Licht und andere die Erzeugung bez. Verwandlung des Lichtes betreffende Erscheinungsgruppen besser verständlich erscheinen unter der Annahme, dass die Energie des Lichtes diskontinuierlich im Raume verteilt sei. Nach der hier ins Auge zu fassenden Annahme ist bei Ausbreitung eines von einem Punkte ausgehenden Lichtstrahles die Energie nicht kontinuierlich auf grösser und grösser werdende Räume verteilt, sondern es besteht dieselbe aus einer endlichen Zahl von in Raumpunkten lokalisierten Energiequanten, welche sich bewegen, ohne sich zu teilen und nur als Ganze absorbiert und erzeugt werden können".

Further, in fact the quantisation of the energy of EM-field was not only suggested but proved in [2]. Moreover, the expression for the energy of EM-field quanta was obtained. It is the following

$$E(\nu) = \frac{R\beta}{N}\nu, \tag{2.1}$$

where R, N, β are constants, at that, the only numerical value of the constant β was not obtained [R is absolute gas constant, N is Avogadro constant], although the expression for the average value of the energy of the blackbody radiation $E(\nu)$ was given, from which the numerical value of β can in principle be found in the same way which was done in the work [1]. Along with the phototoeffect explanation the Stokes rule for a luminiscence was grounded in [2] from quantised EM-field positions.

Therefore, the foregoing consideration seems to be strongly step-up the historical contribution of Einstein into quantum physics. It was a new physical paradigm, at that rather well grounded in contrast to the prevalent opinion on the significance of the work [2] leading to the explanation of a phototoeffect only and even in the suggestion only of a light quanta existence.

Let us concern the basic quantisation paradigm itself introduced in the physics by Planck. We have to remark for the sake of a historical truth that the idea of an absorption or emission of the energy of EM-field with material oscillators by discrete portions was in fact proved by Planck, that is, the term "postulated" is not correct (the words of the type "Max Planck postulated the discreteness, or "Planck postulated, that the oscillators in the walls of the cavity can only absorb or emit radiation in discrete units" and so on are often occured in the scientific literature and textbooks, see, for instance, [17]). Really, the proof was based the only on the following: "Die Hypothese, welche wir jetzt der weiteren Rechnung zu Grunde legen wollen, lautet folgendermassen: Die Warscheinlichkeit W dafür, dass die N Resonatoren insgesamt die Schwingungsenergie U_N, besitzen, ist proportional der Anzahl $\mathfrak{R}$ aller bei der Verteilung der Energie U_N auf die N Resonatoren möglichen Complexionen; oder mit anderen Worten: irgend eine bestimmte Complexion ist ebenso wahrscheinlich, wie irgend eine andere bestimmte Complexion.["The hypothesis, which we now will base on the subsequent calculations is formulated in the following way: the probability W of that, that N oscillators taken together possess by the vibration energy U_N, is proportional to the number $\mathfrak{R}$ of all possible Complexions by the distribution of the energy U_N on N oscillators or in other words - any definite Complexion has the same probability with every other Complexion (the term "Complexion" Max Planck elucidates: "Die Verteilung der P Energieelemente auf die N Resonatoren nur auf eine endliche ganz bestimmte Anzahl von Arten erfolgen kann. Jede solche Art der Verteilung nennen wir nach einem von L. Boltzmann für einen ähnlichen Begriff gebrauchten Ausdruck eine "Complexion". [The distribution of the P energy elements $\{$that is energy quanta in modern terminology$\}$ on N oscillators can be produced by the only finite numbers of the ways. Each given way we will call in accordance with the similar notion, used by L. Boltzmann a "Complexion"]. Planck writes further : "Ob diese Hypothese in der Natur wirklich zutrifft, kann in letzter Linie nur durch die Erfahrung geprüft werden [Whether the given hypothesis is in the Nature really taking place, it can be verified first of all by an experiment]". Let us concern the proof itself. Planck [1] has derived two independent expressions for the entropy of the absorption or emission processes by material oscillators. They are the following

$$S_N = kN[(1+\frac{U}{\epsilon})\log(1+\frac{U}{\epsilon}) - \frac{U}{\epsilon}\log(\frac{U}{\epsilon})], \tag{2.2}$$

and

$$S = f(\frac{U}{\nu}), \tag{2.3}$$

where ϵ is the energy element (energy quantum) value, S_N is the entropy of N independent oscillators, S is the entropy of an individual oscillator, ν is the oscillator frequency. It is seen from (2.3) that the entropy of oscillators in any diathermic medium is the function of the only one argument $\frac{U}{\nu}$, that was accentuated by Planck. It is followed then by the comparison of the expressions (2.2) and (2.3) mathematically strictly the relation

$$\epsilon = h\nu, \tag{2.4}$$

where h has to be the universal constant. Its value, equaled to $6.55 \times 10^{-27}\ erg \times s$ was also determined by Planck [1]. It is the main result of the paper (1), owing to the given result the new, quantum era in the physics was started.

The above cited hypothesis, used by Planck, can also be grounded. Really, the equal probability of Complexion distribution means that the absorption (emission) process for every from N independent oscillators, distributed in a space, will be described by the same characteristics independently of the individual oscillator space location and the starting absorption (emission) time moment. So, we obtain that the equal probability of Complexion distribution will be realised, when the free space and time are homogeneous. In other words, the proof of the Planck hypothesis aforecited results from the homogeneity of Minkowsky space. The homogeneity of the space and time was grounded later in comparison with the paper [1] appearance, just, after publishing in 1918 by Nöter [9] her famous theorem, which being to be applied to the symmetry study of the time and space has indicated on their homogeneity, since the only in the given case the experimentally very good confirmed conservation laws of the energy and impulse in the mechanics are valid. It is understandable why the given small step to the entirely mathematically strict proof of the relation (2.4) was remained to be not traversed in 1900. Moreover, it was remained to be not traversed up to now.

So, it is given the completion of the proof of the famous Planck relation (2.4) in his conceptual consideration.

The second physical phenomenon, indicating on the quantum nature of EM-field is Compton effect, which was experimentally thoroughly studied for the first time by Compton [10] in 1922. Compton [11] and independently Debye have proposed the elementary theoretical explanation of the phenomenon observed on the base of the corpuscular nature of X-rays. The analysis has shown that the impulse of EM-field is also quantised. In other words, it was concluded, that light quanta, possessing by the energy $\hbar\omega$ possess also by the impulse, corresponding to the given energy, equaled to $\vec{p} = (\hbar\omega/c)\vec{e}$, where $\vec{e}$ is the unit vector in the propagation direction.

It is interesting, that the independent conclusion on the the impulse possession by light quanta, the value of which is dependent on the energy quantum value is resulted from experiments of P N Lebedev [12] on the pressure of light, which were performed already in 1901, that is substantially earlier in comparison with Compton experiments. Really, Lebedev's experiments have verified with high certainty the existence of the pressure of light, described by the following expression

$$P = \frac{E}{c}, \tag{2.5}$$

which means that to any portion E of the light energy is set up in the correspondence the mechanical impulse P. Taking into account the known relation for the energy of light quanta, we obtain

$$P = \frac{h\nu}{c}, \tag{2.6}$$

in full correspondence with independent Compton results.

There were revealed very interesting properties of the light flux in the experiments on the interference and diffracion of the light described in [13, 14]. It has been found that at very low light intensities an interference pattern is not appeared. At the same time, the atoms of free silver are appeared on a photographic plate in the place of photon falling. They represent themselves an embryo, which is much smaller than a light wave length. The particle properties of the light show up in the birth of free silver atoms on a photographic plate, one by one. At the same time, when the light intensity is rather large an interference pattern has been shown up. The attempt to explain the given results was undertaken in the book [14] in the following way. The authors write: ”In the interference process (e.g. in two-slit experiment) the photon must have been influenced by the locations of both slits, since the interference pattern depends on the distance between them”. From hence the authors conclude that ”the photon must have occupied a volume larger than the slit separation”. The authors continue further: ”On the other hand, when it fell on the photographic plate the photon must have become localized in the tiny volume of the silver embryo”. The explanation of the given fact according to [14] consist in the presence of ”collapse of wave function” and ”reduction of the wave packet” processes. They conclude: ”The wave properties of the photon show up in the fact that the probability of the collapse at a certain place on the photographic plate (and the accompanying birth of a silver atom there) is proportional to the light intensity”.

The explanation above cited seems to be very vague. It is not understandable, how any elementary particle can have simultaneously very different sizes being to be not subjected to any external effects. We take in mind that the presence of the dependence of the probability of the photon size collapse on the light intensity, which was concluded in [14], is in fact the direct indication on the interaction between photons within the frames of the model proposed in [14]. It is well known, however, that all quantum optics effects can be explained in the suggestion of noninteracting between themselves photons. However, even on the assumption of some interaction between photons the very strong change in the photon size seems to be unreal.

On the other hand, the suggestion on the size of the photon larger than the slit separation itself contradicts both the theoretical and independent experimental results (see the next Section for details). The results described in [14] is the good example for the display of the reality of a rather complicated structure of EM-field, the Fermi liquid model of which is recently proposed in [15] (see the next Section, where the correct explanation of the aforedescribed results is represented on the base of the given model and the evaluation of the photon size is presented).

It is known at present, that there is along with the photoeffect and Compton effect a number of other quantum optics phenomena, which can be described the only with the regard for the EM-field quantization, the main of which are briefly reviewed below.

The very interesting consequence of the EM-field quantization is the appearance of the vibrations which correspond to zeroth energy, so-called vacuum fluctuations. Vacuum fluctuations do not have any classical analogue and they determine very many interesting quantum optics phenomena. For example, spontaneous emission can be explained to be a result of an atom ”stimulation” by vacuum fluctuations.

Let us remark that the results of a fully quantum consideration are quite different from the results, obtained by means of the semiclassical theory of the interaction of EM-field with an atom, in which the atom is considered quantum-mechanicaly, but EM-field is considered clasically, even in the case when vacuum fluctuations are included fenomenologically into semiclassical consideration. It is very good demonstrated in [16], see, for instance, the example of the task on quantum beats [16], that outlines clearly the range of the applicability of the semiclassical approach.

The quantisation of EM-field is necessary for the explanation along with a spontaneous emission phenomenon mentioned above of other quantum optics phenomena - Lamb shift, Casimir effect, an entaglement of the states [16, 17]. It allows also to explain the value of linewidths of the lasers' emission, to explain the observation of nonclassical squeezed states of EM-field and to give the correct desription of a complete statistics of laser photons [16, 17].

Further, the QED model for a multichain coupled qubit system proposed in [18] predicts that by a strong electron-photon interaction the quantum nature of EM-field can become apparent in any stationary optical experiment. The conclusion is based on a new quantum physics phenomenon the space propagation of quantum Rabi oscillations, which has been theoretically predicted in [19] for the systems with a strong electron-photon interaction. The notion of the new quantum objects - rabitons, that is, the new type of quasiparticles, has been introduced in [19]. It was theoretically predicted in [18] that the rabiton formation can give an essential contribution in the stationary spectral distribution of Raman scattering (RS) intensity, spectral distributions of infrared (IR), visible, or ultraviolet absorption, reflection, and transmission intensities. The given prediction was experimentaslly confirmed in [20], where the additional lines corresponding to the Fourier transform of the revival part of the time dependence of the integral inversion were identified. In other words, the lines, the appearance of which in stationary RS and IR measurements is determined by the formation and the propagation of quantum Rabi corpuscles - rabitons have been registered and/or identified in a number of quasi one dimensional and two-dimensional carbon systems. Especially interesting, that additional lines are observed the only in experiments, when the coherent state of the electronic system, interacting with an external EM-field is retained, and they disappear (in distincton from main usual lines) by the violation of the coherence, which was experimentally achieved by the adjustment of spectra registration conditions, corresponding to the stochastic regime [20].

It seems to be appropriate to draw the attention, that the transition to the stochastic behaviour is characteristic for quantum systems. For instance, the authors of [21] have theoretically considered the chaos induced by a quantization. They showed that two-dimensional billiards with point interactions inside exhibit a chaotic nature in the case of quantum systems, although their classical counterparts are non-chaotic. They indicate also, that quantum billiard considered is a natural starting point for examining the particle motion in microscopic bounded regions and that the rapid progress in the microscopic and mesoscopic technology makes it possible to realize given settings.

So we can conclude, that the observation of the stochastic behaviour itself of the studied optical systems is the strong indication on the necessity of a full quantum description of the processes in a joint system $\{$EM-field + matter$\}$.

In spite of the rash development of quantum optics the base method for the theoretical descripion - canonical Dirac quantisation method [7], proposed in 1927, has remained a very long time without any changes. At the same time, Dirac himself has accentuated, that the theory proposed does not sufficiently strict quantum-relativistic theory and the main weakness of the theory is that the time is considered, being to c-number, instead of, rather than to consider it symmetrically with the space coordinates [7]. Nevertheless, Dirac has concluded, that the theory proposed describes fairly satisfactorily the emission of a radiation and the reaction of the radiation field on the emitting system. Dirac has used the same method for the description of the quantum dispersion [22]. In succeeding years, many theoretical results have been obtained in quantum electrodynamics by using of Dirac quantisation method, which were rather well agreeing with experimental data. The method was called canonical, and the impression arises, that the researchers in the field forgot without a trace the Dirac's remark, that the method proposed is in fact semi-quantum-relativistic, that is, being to be local relatively the time coordinate, it has the global character relatively the space coordinates. Really, it is easily to find an explicit form for the dependencies of operator functions $\hat{a}_\alpha(t)$ and $\hat{a}^+_\alpha(t)$ on the time by the canonical quantisation. It has been done in [23]. They are the following

$$\begin{aligned} \hat{a}^+_\alpha(t) &= \hat{a}^+_\alpha(t=0)e^{i\omega_\alpha t}, \\ \hat{a}_\alpha(t) &= \hat{a}_\alpha(t=0)e^{-i\omega_\alpha t}, \end{aligned} \tag{2.7}$$

where $\hat{a}^+_\alpha(t=0), \hat{a}_\alpha(t=0)$ are constant, complex-valued in general case, operators.

The physical sense of operator time dependent functions $\hat{a}^+_\alpha(t)$ and $\hat{a}_\alpha(t)$ according to commonly accepted interpretation is well known. They are creation and annihilation operators of the α-mode photon in multimode EM-field [see further, however, the correction of the physical sense of the given operator functions, determined by proved revival of photons in absorption processes]. They are continuously differentiable operator functions of a time. It means, that the time of photon creation (annihilation) [in commonly accepted at present terminology] can be determined strictly, at the same time, operator functions $\hat{a}^+_\alpha(t)$ and $\hat{a}_\alpha(t)$ do not curry any information on the place, that is, on space coordinates of a given event, confirming the space-global character of the given semi-quantum-relativistic quantisation method.

Let us also remark, that the very similar viewpoint concerning the status of time-coordinate in quantum mechanics (QM) was advanced by Schrödinger [24]: "Ich möchte wiederholen, dass wir eine QM, deren Aussagen nicht für scharf bestimmte Zeitpunkte gelten sollen, nicht besitzen. Mir scheint, dass dieser Mangel sich gerade in jenen Antinomien kundgibt. Womit ich nicht sagen will, dass es der einzige Mangel ist, der sich in ihnen kundgibt. Dass die "scharfe Zeit" eine Inkonsequenz innerhalb der QM ist und dass ausserdem, sozusagen unabhängig davon, die Sonderstellung der Zeit ein schweres Hindernis bildet für die Anpassung der QM an das Relativitätsprinzip, darauf habe ich in den letzten Jahren immer wieder hingewiesen, 1eider ohne den Schatten eines branchbaren Gegenvorschlags machen zu können" [I would wish to repeat, that we don't have QM, the substance of which would be regarded to not strictly determined time moments. It seems to me, that the given disadvantage (demerit) is displayed in its contradictions. I don't wish to say, that the given demerit is only one, which is revealed in them. I have time and again pointed out in the last years, [25, 26, 27], unfortunately do not making the least counter-offer, that the "exactly-defined (sharp) time" is the inconsequence inside of QM, and that moreover, so to speak, independently because of that, the special status of the time leads to an impediment in matching of QM with the relativity principle].

The natural question arises, why the remarks and indications of two from the three main founding fathers of the quantum theory fundamentals were remained without any attention from the side of the researchers in the field. It seems to be connected with Pauli's conclusion, based on well known his theorem, that the introduction of an time operator $\hat{T}$ must fundamentally be abandoned and that the time t in quantum mechanics has to be regarded to be an ordinary number [28]. In other words, the consequence of Pauli's theorem is the inequality in rights of a time coordinate, that is ict coordinate in Minkowski space in comparison with space coordinates for a description of quantum systems, which in its turn has led in the standard formulation of quantum theory to that, that the time is considered to be not a dynamical variable, but a mere parameter marking the evolution of a quantum system, that is, the time is believed to be an external variable, which is independent on the dynamics of any given system. Recently, Pauli's theorem was reconsidered. In particular, it has been proved [29, 30], that in quantum theory to classical variable "time", in contrast to the conclusion of Pauli, can be put in the correspondence the self-adjoint time operator, like to space coordinates, energy, impulse et cetera. Thus, the equality in rights of time [ict]-coordinate and space coordinates was reestablished. It is also an additional confirmation to the confirmation following from results of an applicability of Nöther theorem, above described, that the Minkowski space is a single whole, that is, it is the homogeneous physical object.

The canonical Dirac quantisation method was developed in the work [23] in three aspects. The first aspect is its application the only to observable quantities. The second aspect is the realization along with the well known semi-quantum-relativistic time-local quantisation of the space-local quantisation, which remains, however, also semi-quantum-relativistic being to be time-global. The main result is the development of the fully quantum-relativistic space-time-local quantisation method. It is the third aspect. In other words, it has been proved theoretically, that along with an indication of the time instant of a photon creation (or annihilation) [in commonly accepted at present terminology] the space coordinate can be also determined. Just the given result allows to finish the above indicated discussion about the possibility to describe photons by field scalar functions, which has been taking place over a long period of time, see below. It will be shown, in accordance with aforesaid remark that the given problem, being to be emerging at beginning of the quantum physics era can be positively solved - any photon state can be described by a field scalar function, which can be built like to field scalar functions of the other particles, for example, like to the field scalar function of the neutrino.

The detailed argumentation of the given conclusion and the proof of the concept of the photon being to be the genuine particle is the main aim of the given work.

The semi-quantum-relativistic character of Dirac canonical quantisation method has expressed in its role on the introduction of the field scalar function of the photon and on the conception of the photon in electrodynamics itself (see below the brief description of the discussion on the notions of the photon field scalar function and the photon conception to be the genuine particle and the arguments, allowing to crown the discussion in favour of the given notions).

The term ”wave function” in the description of corpuscular objects, widely used in the quantum physics literature, can give rise to misunderstandings. We have to concern the history of the given term and its genuine physical sense. The notion ”wave function” was introduced in quantum physics by Schrödinger. The foundations of ”wave” variant of quantum mechanics are represented in the famous four works [31, 32, 33, 34]. Schrödinger's theory was analysed recently from the field theory concept positions in [35]. It was shown in [35], that the Schrödinger's quantum mechanics theory is the development of the classical mechanics theory for the case when the dynamics of mechanical systems is not determined by the gravitation field but it determines by the electromagnetic field mainly. The Schrödinger's quantum mechanics theory corresponds in the modern terminology to the field theory of elementary particles, however, in its initial semiintuitive stage. The objects of Schrödinger's theory are elementary particles or systems of elementary particles together with fields, associated with given particles. In fact, Schrödinger himself understood (maybe on the semiintuitive level), that his theory is in fact the field theory [in modern terminology, we have to add once again, that the only on its starting stage]. The proof for the given viewpoint is given in [35] and it is the following. Please, at first, the Schrödinger's own comment to the name both for differential equation for the function $\Psi(q_1, q_2, ..., q_N, t)$ and for the function $|\Psi(q_1, q_2, ..., q_N, t)|^2$ itself. In the fourth (last) part of the series of works ”Quantisierung als Eigenwertproblem” Schrödinger writes [34]: ”Wenn wir also Gleichung (1) oder (1') [that is, in the modern terminology for both the stationary Schrödinger equation, given by

$$\triangle\Psi(x, y, z) + \frac{8\pi^2[E - V(x, y, z)]}{h^2} = 0, \tag{2.8}$$

and the nonstationary Schrödinger equation, the dependence of $\Psi(q_1, q_2, ..., q_N, t)$ on a time in which is determined by

$$\exp[(\frac{2\pi E_l t}{h} + \theta_l)i], \tag{2.9}$$

we wish to remark, that the only given equations are used in the modern nonrelativistic quantum mechanics in the linear case] gelegentlich als Wellengleichung bezeichnet haben, so geschah das eigentlich zu Unrecht, sie wäre richtiger als ”Schwingungs-” oder ”Amplituden”-gleichung zu bezeichnen. Wir fanden aber mit ihr das Auslangen, weil ja an diese das Sturm-Liouvillesche Eigenwertproblem sich knüpft - ganz ebenso wie bei dem mathematisch völlig analogen Problem der freien Scbwingungen von Saiten und Membranen - und nicbt an die eigentliche Wellen-gleichung”.

In the cited work Schrödinger introduces the new name for the function $|\Psi(q_1, q_2, ..., q_N, t)|^2$ - ”Feld- skalar” [field scalar] instead of ”wave function”, just to the given name Schrödinger gives the preference. It indicates according to [35] on the rather deep his semiintuitive insight in the field, testifying to his understanding of the relation of the theory developed with the field theory and on its corpuscular aspect description mainly.

Let us represent the interpretation by Schrödinger himself of the real physical meaning of the field scalar function $|\Psi(q_1, q_2, ..., q_N, t)|^2$. Schrödinger argues that in the case of the hydrogen atom (a one-body problem) [36] ”it is possible to compute fairly correct values for the intensities, for example, of the Stark effect components by the following hypothesis: the charge of the electron is not concentrated in a point, but is spread out through the whole space, proportional to the quantity $|\Psi(q_1, q_2, ..., q_N, t)|^2$. It has to be born in mind, that by this hypothesis the charge is nevertheless restricted to a domain of, say, a few Angstroms, the function $|\Psi(q_1, q_2, ..., q_N, t)|^2$ practically vanishing at greater distance from the nucleus. The fluctuation of the charge will be governed by $|\Psi(q_1, q_2, ..., q_N, t)|^2$, applied to the special case of the hydrogen atom”.

The following comment is given in [35] to the hypothesis on the charge distribution, described by the continuous field scalar function: "On the one hand, it is the direct consequence of the field character of the Schrödinger's theory. On the second hand, Schrödinger in fact suggests, that the fields associated with elementary particles incoming in the atomic structure have a new observable quantity - continuosly distributed in a space the scalar charge function. The given hypothesis was recently proved in the works [37, 38] for the case of an electromagnetic field. Consequently, the conclusion on a charge spread out through the whole space, proportional to the quantity $|\Psi(q_1, q_2, ..., q_N, t)|^2$ seems to be correct up to distances by their decreasing, being to be comparable with a nuclei size, since by a small distances for the charge distribution instead of the elctromagnetic forces the forces of a strong interaction are responsible. On the third side, the indication, that the charge distribution is restricted to a domain of a few Angstroms, and that the scalar function $|\Psi(q_1, q_2, ..., q_N, t)|^2$ is practically vanishing at greater distance from the nucleus confirms additionally, that the given part of the Schrödinger's theory is really describes the corpuscular aspect in the dual picture considered. Further, Schrödinger gives the generalization of the concept above considered [34, 36]: "Now how are these conceptions to be generalized to the case of more than one, say of N, electrons? Here Heisenberg's formal theory has proved most valuable. It tells us though less by physical reasoning than by its compact formal structure that equation giving a rectangular component of total electric moment has to be maintained with the only differences that

(1) the integrals are $3N$-fold instead of three fold, extending over the whole coordinate space;

(2) e_z has to be replaced by the sum $\sum e_i z_i$, i.e. by the z-component of the total electrical moment which the point-charge model would have in the configuration $(x_1, y_1, z_1; x_2, y_2, z_2; ...; x_N, y_N, z_N)$ that relates to the element $dx_1, ...; dz_N$ of the integration". It was taken into account the intimate connection proved by Schrödinger between the Heisenberg-Born-Jordan matrix and his own theories. "The achievement of the present theory - which may be imperfect in many respects" - writes Schrödinger - "seems to me to be that by a definite localization of the charge in space and time we are able from ordinary electrodynamics really to derive both the frequencies and the intensities and polarizations of the emitted light. All so-called selection principles automatically result from the vanishing of the triple integral for the electric dipole moment in the particular case". The argumentation aforegiven allowed to Schrödinger to formulate the following hypothesis concerning the physical meaning of the field skalar function $\Psi(q_1, q_2, ..., q_N, t)$ in the case of N-electron system: "The real continuous partition of the charge is a sort of mean of the continuous multitude of all possible configurations of the corresponding point-charge model, the mean being taken with the quantity $|\Psi_n(q_1, q_2, ..., q_N, t)|^2$ representing itself a sort of weight-function in the configuration space".

It is concluded in [35]: "Therefore, it is clear, that the Schrödinger's interpretation of the field skalar $\Psi(q_1, q_2, ..., q_N, t)$, introduced in quantum theory by himself, differs drastically from its interpre-tation in modern textbooks on quantum mechanics. Schrödinger does not connect $|\Psi(q_1, q_2, ..., q_N, t)|^2$ with a probability at all. We have to accentuate, that the notion of the probability cannot be used for fast passing physical processes, see for details [39]. At the same time, it can be argued, that the Schrödinger's interpretation can be retained even in the given case, allowing to describe in the principle the single event.

According to the proposal of Born [40], the field skalar function $\Psi(q_1, q_2, ..., q_N, t)$ was used to describe the amplitude of the probability of finding the electron in a space. [We have to remark that it is not the classical mathematical notion, since the notion of the complex amplitude of the probability is absent in the mathematics]. The statistical interpretation of quantum theory, proposed by Born, rejects describing a single event but only the probabilities in repeated experiments. This is too big of a sacrifice according to Schrödinger opinion, and it is responsible for some of the major problems of the foundations of the whole theory".

Dirac gives the comment to aforeindicated Born suggestion, conserning the statistical interpretation of the Schrödinger's quantum theory in [8]. He writes directly that the notion of the probability by no means enters in a definitive description of the mechanical processes. The probabilistic description of the mechanical processes is possible, according to Dirac opinion, the only in the case, if the initial information is given already in a probability language.

Commenting the Schrödinger's quantum theory we wish to draw attention on the aspect of the given theory, which seems to be unknown for a wide readership. The existence of an own discrete structure of the fields associated with elementary particles, incoming in the structure of atomic dynamical systems and determining their properties, was taken into account in the phenomenological Schrödinger's theory in an implicit form by the other wave function, being to be quite differet from the field skalar function $\Psi(q_1, q_2, ..., q_N, t)$. It is the wave-function $\psi(x, y, z, t)$, which was represented in the form [36]

$$\begin{aligned}\psi(x, y, z, t) = A(x, y, z)\sin(W/K) = \\ A(x, y, z)\sin[\frac{-Et}{K} + \frac{S(x, y, z)}{K}],\end{aligned} \tag{2.10}$$

where $A(x, y, z)$ is an "amplitude" function. The action W is represented in (2.10) in the form

$$W = -Et + S(x, y, z), \tag{2.11}$$

According to [36] "the constant K must be introduced and must have the physical dimension of action (energy$\times$time), since the argument of a sine must always be a pure number". "Now", - Schrödinger argues, - "since the frequency of the wave (2.10) is obviously

$$\nu = \frac{E}{2\pi K}, \tag{2.12}$$

supposing K to be *a universal constant*, independent on E and independent on the nature of the mechanical system, because if this be done and K be given by the value $h/2\pi$, then the frequency ν will be given by

$$\nu = \frac{E}{h}, \tag{2.13}$$

where h is Planck constant. Thus, the well known universal relation between energy and frequency is arrived at in a rather simple and unforced way".

Here we have to remark, that just the expression (2.10) is the starting qenuine wave equation, which allows to describe the wave properties of rather complicated systems of quantum fields, which, being to be represented by quantum liquids allow to represent the model of atoms being to be the superposition of the corpuscles of corresponding fields in spirit of Standard Model, that is, the superposition of the field systems, corpuscles in which are elementary particles producing the atomic nuclei - protons and neutrons, for which the strong interactions are responsible and the field system, corpuscles in which are electrons, for which the electromagnetic interactions are responsible. Therefore, in fact, Schrödinger has put into consideration two different field scalar functions, the first of which is genuine wave function and it is determined by the expression (2.10), the second field scalar function is $\Psi(q_1, q_2, ..., q_N, t)$. It is determined from the solution of the Schrödinger equation, corresponding to an atomic dynamic system studied and it characterises the corpuscular properties of the given atomic dynamic system. The term "wave function" in the application to it, always and entirely used in the literature on quantum mechanics at present, seems to be not adequate and it has to be replaced in accordance with Schrödinger definition on the term "field scalar function".

Thus, the mathematical aspect of a corpuscular-wave dualism was represented in the Schrödinger's quantum theory in a quite correct form. Two independent from each other scalar functions describing correspondingly wave and corpuscular aspects were introduced by Schrödinger. The only physical nature of the phenomenon of a corpuscular-wave dualism itself has seen to him rather vague. For the case of EM-field the genuine wave function was represented in [35] in the form

$$\begin{aligned}\psi(x, y, z, t) \equiv \psi(\vec{r}, t) = \\ \sum_{i=1}^{Q}\{u_{\vec{k}_j}(\vec{r})\exp\vec{k}_j\vec{r}\sin[-2\pi\nu_j t + \frac{S_j(\vec{r})}{K_j}]\},\end{aligned} \tag{2.14}$$

where K_j is given by the value $h/2\pi$, which is independent on j, and $\nu_j = \frac{E_j}{h}$, the functions $u_{\vec{k}_j}(\vec{r})$, $j = \overline{1, Q}$, have the period of the sublattice j. The structure of EM-field is modelling by the sets of 1D rays, the own structure of each ray is discrete - 1D-lattice of spin-1 bosons. In other words, the structure of EM-field in boson model used resembles the structure of the carbon frame of organic polymers like to *trans*-polyacetylene in the matter. The relation (2.14) indicates that the wave function $\psi(\vec{r}, t)$ represents itself the set of Bloch-like waves. Just, the given function allows to describe correctly the wave properties of the light, including the interference and the diffraction.

Consequently, to describe correctly the corpuscular-wave dualism it is necessary to use the full variant of Schrödinger's theory, taking into consideration two scalar functions. The wave function $\psi(\vec{r}, t)$ is responsible for the wave aspect in a dynamics of atomic systems. In the case of dynamics studies with the participation of the elementary particles - photons it has the view, given by the relation (2.14). The relation (2.14) is based both on the Schrödinger's theory and on the theory considering EM-field, being to be quantum 1D Fermi liquid, the theory of which is developed in [15]. It seems to be reasonable to suggest, that the relations, analogous to (2.14) seem to be correct for the fields, associated with other elementary particles, incoming in the structures of atomic systems.

We draw attention once again, that the field scalar function $\Psi(q_1, q_2, ..., q_N)$ above considered is responsible for the description of corpuscular properties of atomic systems. The concrete analytical expression for the given function is obtained by means of the solution of the corresponding Schrödinger equation. It is clear, taking into account the resemblance of the laws of quantum mechanics and both geometrical and undulatory optics, that just the electromagnetic forces are determining forces in the dynamics of quantum mechanics systems. The fact is that the dynamics of classical mechanics systems is determined by taking into account the gravitation field. At the same time, the role of the gravitation field for the dynamics of elementary particles with rather small masses seems to be too little, in order to have any substantial effect in the dynamics of quantum mechanics systems.

From the aforegoing consideration, the direction for the main development of the quantum mechanics is crystallized. It is the way of a quest for the description of a single event. It can be realised to some extent by using, in particular, the interpretation of the field scalar function, proposed by Schrödinger himself. However, it seems to be necessary the elaboration of new versions of quantum mechanics with the given aim.

We also wish to remark in passing, that in [35] the conclusion on the status of the second main postulate of quantum mechanics is given. The second main postulate is formulated in texbooks on quantum mechanics in the following way, in particular, in [41]: "The state of a system can be described by a certain (generally speaking complex) function of coordinates $\Psi(q)$, at that the square of the module of this function determines the probability distribution of the coordinates' values: $|\Psi(q)|^2 dq$ is a probability of that, that a measurement carried out under a system reveals the values of the coordinates in an element dq of the configuration space. The function $\Psi(q)$ is called the wave function". Its formulation in all textbooks has to be represented in the form of the proved statement, but not a postulate, since the hypothesis of Schrödinger on the existence of the field scalar function, being to be observable quantity, just charge density, is strictly proved for the case of EM-field, the role of which is argued to be decisive for the dynamics of the atomic systems. Moreover, it is shown, that it actually describes the state of the system, since the full set of the functions for the description of EM-field is consisting of four scalar functions or equivalently, from one scalar and one vector functions. The information, which is given by an observable vector function of EM-field - field strength function - is included in an implicit form in Schrödinger equation for the field scalar function, that is, it is taking into consideration too. Therefore, the second main postulate in Schrödinger formulation [more strictly, his name according to Schrödinger was hypothesis] can be mathematically strictly grounded, but in the popular probabilistic form used in modern textbooks on quantum theory it cannot be proved. The probabilistic theatise, proposed by Born [40] is true in a number of special cases, quite correctly indicated by Dirac [8]. At the same time the given cases embrace the wide range of quantum physics phenomena.

3 Concept of Photon Status

Let us concern of the status of the photon in the modern physics at all. The researchers, dealing in the field of elementary particles, consider the photon to be the genuine particle being self-evident, see, for instance, [42]. Within the frames of the Standard Model of particle physics the photon is considered to be the messenger of the electromagnetic interaction to which are subject charged particles. In other words, the interaction of electrically charged particles is realised within the frames of the Standard Model through the exchange of photons [42]. Let us remark, that the Standard Model, being to be the quantum and relativistic theory which describes in a unified framework the electromagnetic, weak and strong forces of elementary particles is based on a very powerful principle, local or gauge symmetry. In the given model to each particle is associated a field that has a given number of degrees of freedom. It is interesting, that according to the Standard Model the field associated to the photons has two degrees of freedom [42]. Let us cite the article [43] in the aspect, concerning the differences between the photons and the messengers of the weak force interaction, that is, W and Z bosons and their relation to Higgs boson: "The Higgs boson is a massive elementary particle predicted to exist by the Standard Model. It plays a unique role in the Standard Model, by explaining why the other elementary particles are massive. In particular, the Higgs boson model has to explain why the photon has no mass, while the W and Z bosons are very heavy. Elementary particle masses, and the differences between electromagnetism (mediated by the photon) and the weak force (mediated by the W and Z bosons), are critical to many aspects of the structure of microscopic (and hence macroscopic) matter. The CMS and ATLAS experiments at the Large Hadron Collider (LHC) at CERN in Geneva reported the first experimental evidence of the Higgs boson's existence on July 4, 2012. Subsequently, the Higgs boson mass has been measured to be about 125 GeV." It is seen from the given citate that the photon has the individual place among the genuine elementary particles in the Standard Model and it is considered to be self-evident, that its properties are quite different from the very heavy W and Z bosons. Really, in the concept of elementary particles existing at present "the Higgs boson emerges and disappears by borrowing energy from and returning energy to the particles in the electroweak interaction, respectively. Returning of energy from the Higgs scalar boson to the particles is through the absorption of the Higgs scalar boson by the particles. When a massless particle in the electroweak interaction absorbs the Higgs scalar boson, the Higgs scalar boson becomes the longitudinal component of the massless particle, resulting in the massive particle and the disappearance of the Higgs scalar boson" [44]. According to [44]: "The observed Higgs boson at the LHC is a remnant of the Higgs boson. At the beginning of the universe, all particles in the electroweak interaction were massless. The Higgs boson appeared by borrowing energy symmetrically from all particles in the electroweak interaction. The Higgs boson coupled with all massless particles, including leptons, quarks, and gauge bosons, in the electroweak interaction. All massless particles except photon absorbed the Higgs boson to become massive particles. The asymmetrical returning of energy from the Higgs boson by the absorption of the Higgs boson is called the symmetrical breaking of the electroweak interaction in the Standard Model. In the cases of massive particles, including leptons, quarks, and weak gauge bosons, the Higgs boson disappeared. In the case of massless photon the unabsorbed Higgs boson became the remnant of the Higgs boson. Being specific to the electroweak interaction, the remnant of the Higgs boson could not return the borrowed energy to any other massless particles". So it is established that the photons occupy a peculiar place regarding the interaction with Higgs bosons. From here, taking into account the comparison with the W and Z boson formation, it can be done the reazonable suggestion in that the photons cannot be considered to be the gauge spin-1 bosons of the electromagnetism.

So, the experts in the elementary particles' theory really consider the presence of the place of the photon among the genuine elementary particles to be self-evident, but its place is considered to be peculiar in the relation to the interaction with the Higgs boson.

We have remark that it is existing in the literature the another viewpoint concerning the fundamental building block of our universe. Let us cite the work [45]. "... fundamental question is whether the Higgs boson is indeed God's particle, i.e., the fundamental building block of our universe. To resolve this question, we need to resolve these related questions: 1) How does the Higgs boson fit in and define the structure of the proton and the other elementary particles and the atom? 2) Since the Higgs boson is supposed to endow mass to an elementary particle then its mass must conform to energy conservation, i.e., it has mass. Some advocates of the Higgs boson take the view that it is a number endowed with neither structure nor mass; 3) Then how can it give mass to matter? Thus, there is a fundamental barrier to the Higgs boson being the fundamental building block of matter. Moreover, it is known that in the Cosmos, the cosmological bodies, e.g., stars, galaxies and planets, add up to only 5 percents of the mass of our universe. Where is the remaining 95 percents? What is it and how does the Higgs boson fit in it? There is another formidable barrier. One of the two requirements for such fundamental building block is: it must be indestructible; otherwise, our universe would have been unstable and exhausted a long time ago which was not since it has existed for 8 billion years and has even evolved to higher order with the emergence of new natural laws such as biological laws. We have seen its destruction at CERN!" Further, the author of [45] indicates on the other requirement for the fundamental building block - every piece of matter is reducible to it which, in effect, would require that there is only one building block, like to that there is only one electron replicated at different times and places but having exactly the same composition, structure, behavior and properties. The author of (45) continues "It is not clear if the Higgs boson satisfies this requirement", he writes, that the claim that the Higgs boson can explain the origin of our universe is quite a long, long hypothesis, referring on the opinion in [46]: "Experimenters will have to verify that the new particle (Higgs boson) is at a spin-0 Higgs boson. Next, they must test how the Higgs boson interacts with other particles to high precision. At this writing its couplings do not quite match predictions, which could be just a statistical fluctuation or a sign of some deeper effect. Meanwhile, experimenters have to keep taking data to see whether more than one Higgs boson exists". According to the opinion of Escultura [45] not the Higgs boson but the superstring is the fundamental building block of matter.

For the work presented independently of the viewpoint concerning the fundamental building block of our universe is essential that the experts in the elementary particle physics consider the photon to be the genuine particle being self-evident.

Let us analyse the development of the viewpoint on the photon status in the quantum electrodynamics. Power and Kramers write quite directly, that the photon cannot be considered being to be the relativistic particle [47, 48]. Correspondingly, concerning the wave functions of the photons [we use the traditional terminology for the field scalar function], Power writes, that, strictly speaking, the wave functions of the photons are not existing. The main argument is the following. The fields $\vec{E}$ and $\vec{H}$ being to be satysfuing to Maxwell equations can be described according to his opinion by the real-defined functions. He concludes further, that they cannot be the solutions of the Schrödinger equation, which is always the complex-defined function. We have to remark, that the given argument can be easily parried now. It has been shown by the study of the symmetry of Maxwell equations, that the quantised EM-field is always described the only by complex-defined field functions [23]. In other words, they can be represented to be the solutions of the corresponding Schrödinger equation. Bohm [49], in its turn, writes - strictly speaking, the function, describing the probability to find the light quantum, for instance, in space interval $(x, x + dx)$ does not exist. Really, the given conclusion is quite correct within the frames of semiquantum Dirac quantisation method over its space-global character, and it becomes to be incorrect by the photon field description within the quantisation method, proposed in [23], which has both the space and the time local character. It is shown in [23], that the operator functions of creation $\hat{a}^+_\alpha(z,t)$ and annihilation $\hat{a}_\alpha(z,t)$ [here we also use the traditional terminology] can be represented in the form

$$\hat{a}^+_\alpha(z,t) = \frac{1}{\sqrt{2\hbar\lambda_0 m_\alpha \omega_\alpha}} \left[m_\alpha \omega_\alpha \hat{q}_\alpha(z,t) - i\hat{p}_\alpha(z,t)\right], \quad (3.1)$$

$$\hat{a}_\alpha(z,t) = \frac{1}{\sqrt{2\hbar\lambda_0 m_\alpha \omega_\alpha}} \left[m_\alpha \omega_\alpha \hat{q}_\alpha(z,t) + i\hat{p}_\alpha(z,t)\right], \quad (3.2)$$

by means of which the local space-time quantisation of EM-field is realized. The variables $\hat{q}_\alpha(z,t)$, $\hat{p}_\alpha(z,t)$ in the expressions (3.1) and (3.2) are canonically conjugated coordinate [amplitude of the normal mode, which has the dimensionality of the length] and impulse operator functions, corresponding to α-mode of quantised EM-field, $\alpha \in N$. The value λ_0 is analogue of Planck constant $\hbar$. Although λ_0 and Planck constant $\hbar$ are equidimensional, however, their numerical coincidence seems to be unobvious, since Planck constant characterizes the "seizure" of the time by propagating of EM-field, while λ_0 characterises the "seizure" of the space. The value ω_α is the circular frequency of EM-field α-mode, m_α is the constant for the fixed mode, which has the dimensionality of the mass and which is introduced for the comparison with the mechanical harmonic oscillator.

The operator functions $\hat{a}^+_\alpha(z,t)$, $\hat{a}_\alpha(z,t)$ in (3.1) and (3.2) satisfy to the relation

$$[\hat{a}_\alpha(z,t), \hat{a}^+_\beta(z,t)] = -i\delta_{\alpha\beta}\hat{e}, \tag{3.3}$$

where $\hat{e}$ is the unit operator in the space of the representation of the functions $\hat{a}^+_\alpha(z,t)$, $\hat{a}_\alpha(z,t)$. Then the probability $dP(z,t)$ to find the light quantum, for instance, in the space interval $(z, z+dz)$ and in the time interval $(t, t+dt)$ is

$$dP(z,t) = |\hat{a}^+_\alpha(z,t)|0\rangle|^2 dzdt, \tag{3.4}$$

where $|0\rangle$ is the vacuum state of EM-field.

The step forward in the concept of the photon to be genuine elementary particle has been done in [16], however some mistakes have been made which don't allow to confirm the given concept. In particular, in [16] is insisted, that there are fundamental differences in the description of the photon to be the elementary particle, despite the marvellous resemblance in motion equations for the photon and for the neutrino. Moreover the authors insist, that the description of the photon to be the elementary particle is impossible. It contradicts very strongly to the Einstein concept of light quanta to be the particles, theoretically and experimentally grounded by him mainly by means of the photoeffect analysis, that is, with experimental grounds. Let us remember once again that the concept of light quanta to be the particles was considered already by Newton, although the only on the intuitive level without any experimental grounds.

Let us consider "the arguments" in [16] in more details. Scully and Zubairy [16] argue in the following way. They write the relation for the plane wave, polarized in x-direction and propagating in z-direction in the form of

$$\phi(\vec{r},t) = \vec{e}_x \frac{1}{\sqrt{V}} \exp[i(k_z z + \omega_{k_0} t)], \tag{3.5}$$

where V is the volume of the propagation space, k_z is the value of the wave vector $\vec{k_0} = k_z\vec{e}_z$, ω_k is the frequency, corresponding to $\vec{k_0}$. In fact, the relation (3.5) is incorrect, since instead of the scalar function in the left part of the relation has to be the vector function. However, it can be the only misprint. Further, the authors argue, that if to give the additional impulse in the direction x, that is, when a new wave vector $\vec{k}$ will be

$$\vec{k} = k_z\vec{e}_z + k_x\vec{e}_x, \tag{3.6}$$

and to make the field transformation

$$\exp(ik_x x) \tag{3.7}$$

a new function they represent in the form

$$\tilde{\phi}(\vec{r},t) = \vec{e}_x \frac{1}{\sqrt{V}} \exp[i(k_z z + k_x x + \omega_k t)]. \tag{3.8}$$

In the given case, according to the opinion of the authors, the Maxwell equation

$$\nabla \cdot \begin{bmatrix} \vec{\phi}(\vec{r},t) \\ \vec{\chi}(\vec{r},t) \end{bmatrix} = 0 \tag{3.9}$$

is not true. They write

$$\nabla\cdot\tilde{\phi} = \frac{\partial}{\partial x}[\frac{1}{\sqrt{V}}\exp[i(k_z z + k_x x + \omega_k t)]] \neq 0. \tag{3.10}$$

From here the authors have concluded by the comparison with a unrelativistic particle with nonzero rest mass (with electron), that the representation of the photon to be the particle is erroneous. All the argumentation is incorrect. First, the transformation like to $\exp(ik_x x)$ [in general case $\exp(i\vec{k}\vec{r})$] has to be applied to all field functions, that is, to the vector-function $\vec{\chi}(\vec{r},t)$ too, admittedly, $\vec{\chi}(\vec{r},t)$ is invariant in the particular case of the transformation $\exp(ik_x x)$ considered, since the given transformation is the rotation about y-axis, coinciding with the direction of the vector-function $\vec{\chi}(\vec{r},t)$, in the complex plane (ix, z), which can be set up to the real plane (x, z) by biective mapping. Second, the vector-function $\vec{\phi}(\vec{r},t)$ will be rotated on the angle θ, determined by the relation $\tan\theta = \frac{k_x}{k_z}$, that is, it will be directed along a new unit vector $\vec{e}_{x'}$, at that, $(\vec{e}_x\vec{e}_{x'}) = \cos\theta$. Simultaneously, the transformation of z-axis also takes place $z \to z'$. The new direction of a z-axis, that is, z'-direction will coincide with the new vector $\vec{k}$ direction, at that, it is also a new impulse direction. The physical mistake of authors [16] consist in that that they don't take into account that the propagation direction of the free EM-wave is determined by the impulse direction, that is, after the field functions transformation $\exp(ik_x x)$ EM-wave will be propagated along z'-direction. Consequently, instead of the relation (3.10) has to be

$$\nabla\cdot\vec{\tilde{\phi}}(\vec{r},t) = \frac{\partial}{\partial x'}[\frac{1}{\sqrt{V}}\exp[i(k'_z z' + \omega_k t)]] = 0. \tag{3.11}$$

in a full agreement with all Maxwell equations.

Scully and Zubairy [16] consider the second example, which, according to their opinion, is the most significant argument in the favour of the inapplicability of the representation of the photon to be the particle. The second example is regarded to two-quantum transitions. The amplitude of two-quantum detection is [16]

$$\Psi^{(2)}(\vec{r_1},t_1;\vec{r_2},t_2) = \langle 0|\hat{E}^{(+)}(\vec{r_2},t_2)\hat{E}^{(+)}(\vec{r_1},t_1)|\psi\rangle, \tag{3.12}$$

where $\hat{E}^{(+)}(\vec{r_1},t_1)$, $\hat{E}^{(+)}(\vec{r_2},t_2)$ are field annihilation operators, arguments of which are indicating on the probability of the annihilation of the photons in detectors, located in the points $\vec{r_1}$, $\vec{r_2}$ in the time moments t_1, t_2 correspondingly, $|\psi\rangle$ is the two-photon state. It seems to be correct within the frames of an existing quantisation procedure. [See, however, the work [23], the results of which allow to consider another way of looking into the task of two-quantum transitions]. It has been obtained in [16] for the case, when the relaxation rates γ_a, γ_b from the atomic level $|a\rangle$ into the atomic level $|b\rangle$ and from the atomic level $|b\rangle$ into the atomic level $|c\rangle$ correspondingly are satisfying to the relation $\gamma_a \gg \gamma_b$, the following expression

$$\begin{aligned}
&\Psi^{(2)}(\vec{r_1},t_1;\vec{r_2},t_2) = \\
&\Psi_\alpha(\vec{r_1},t_1)\Psi_\beta(\vec{r_2},t_2)\Psi_\beta(\vec{r_1},t_1)\Psi_\alpha(\vec{r_2},t_2) \\
&\Psi_\alpha(\vec{r_i},t_i) = \frac{\mathcal{E}_a}{\Delta r_i}\Theta(t_i - \frac{\Delta r_i}{c})\times \\
&\exp[-\gamma_a(t_i - \frac{\Delta r_i}{c})]\exp[-i\omega_{ab}(t_i - \frac{\Delta r_i}{c})], \\
&\Psi_\beta(\vec{r_i},t_i) = \frac{\mathcal{E}_b}{\Delta r_i}\Theta(t_i - \frac{\Delta r_i}{c})\times \\
&\exp[-\gamma_b(t_i - \frac{\Delta r_i}{c})]\exp[-i\omega_{bc}(t_i - \frac{\Delta r_i}{c})],
\end{aligned} \tag{3.13}$$

where ω_{ab}, ω_{bc} are the frequencies of the atomic transitions $|a\rangle \to |b\rangle$ and $|b\rangle \to |c\rangle$ correspondingly, Δr_i is the distance from an atom to i-th detector, i = 1, 2, $\mathcal{E}_a$, $\mathcal{E}_b$ are constants, $\Theta(t_i - \frac{\Delta r_i}{c})$ is the Heaviside step-like function. From here the authors conclude on the emission of two independent photons, that allows to retain the concept of the photon to be the particle.

Further, the authors of [16] insist, that in the case $\gamma_b \gg \gamma_a$ the concept of the photon to be the particle cannot be retained. They have obtained the following expression for the amplitude of a two-quantum detection in the given case

$$\begin{aligned}&\Psi^{(2)}(\vec{r_1}, t_1; \vec{r_2}, t_2) = \\ &\frac{-\kappa}{\Delta r_1 \Delta r_2} \exp[-i(\omega_{ac} + \gamma_a)(t_1 - \frac{\Delta r_1}{c})]\Theta(t_1 - \frac{\Delta r_1}{c})\times \\ &\exp[[-i(\omega_{bc} + \gamma_b)\{(t_2 - \frac{\Delta r_2}{c}) - (t_1 - \frac{\Delta r_1}{c})\}]\times \\ &\Theta[(t_2 - \frac{\Delta r_2}{c}) - (t_1 - \frac{\Delta r_1}{c})] + [1 \leftrightarrow 2],\end{aligned} \tag{3.14}$$

in which ω_{ac} is the frequency of the atomic transition $|a\rangle \rightarrow |c\rangle$, κ is constant. It is the relation 1.5.44 in [16], from which the authors conclude, that both the events are strongly correlated and the representation of the photons to be the particles is incorrectly.

At the same time, the mathematical structure of the relation (3.14) is equivalent to the the mathematical structure of the relation (3.13), if the constant κ to represent in the form $\kappa = \mathcal{E}'_a\ \mathcal{E}'_b$. It can be factorized like to (3.13), however, the first transition instead of the frequency ω_{ab} has the frequency ω_{ac}. It physically means, that the process of two-quantum transitions in a three level atom by $\gamma_b \gg \gamma_a$ is accompanying by the emission of two photons with the energy corresponding to the distance between the first and the third levels and with the energy corresponding to the distance between the second and the third levels. It means, that the concept of the photons to be the particles can be retained in the given case too.

It is interesting to remark that the authors of [16] themselves by setting forth the Weisskopf-Wigner theory of the spontaneous emission of a two-level atom write: "...the function

$$\Psi_\gamma(\vec{r}, t) = \langle 0|\hat{E}^{(+)}(\vec{r}, t)|\gamma_0\rangle, \tag{3.15}$$

can be interpreted being to be a certain form of the photon wave function. It has been done in the analogue with the particle wave function". The state $|\gamma_0\rangle$ in (3.15) is the EM-field state in the point of the time $t > 0$, which corresponds to the atom, localised at the $\vec{r}_0$ point, $|0\rangle$ is the vacuum state of EM-field, being to be the state of EM-field in the initial point of the time $t = 0$, $\hat{E}^{(+)}(\vec{r}, t)$ is the positive-frequency part of the operator of the electric component of EM-field.

Therefore, it is seen, that the position of Scully and Zubairy is self-contradictory. They, insisting on the one hand on the inapplicability of the representation of the photon to be the particle, have used, on the second hand, the notion of the photon wave function, at that its definition has been done in the full analogue with the definition of the wave function of the well established particle with nonzeroth rest mass, for instance, the electron. In other words, the mathematical analysis has been done quite correctly. Let us remark once again, that the matter concerns the field scalar function, describing the corpuscular properties and the term "wave" for photon wave function has to be used in inverted commas.

In the general case, the field scalar function of the photon can be obtained similarly to the field scalar function of the usual particle, for instance neutrino, that is, it is given by the expression

$$\Psi(\vec{r}, t) = \langle\vec{r}|\psi(t)\rangle, \tag{3.16}$$

representing itself the scalar product of the eigenvector of the position operator (cordinate part) and the vector of the state, giving the time-dependent part. The given representation is possible, since according to the space-time local quantisation method, developed in [23], along with an indication of the time instant of the photon creation (or annihilation) the space coordinate for the given event can be also determined. The given theory is applicable, since the state $|\vec{r}\rangle$ is represented through the creation operator $\hat{\psi}(\vec{r})$, which acting on the vacuum state $|0\rangle$ creates the particle in the space point $\vec{r}$ in accordance with the expression

$$|\vec{r}\rangle = \hat{\psi}^{(+)}(\vec{r})|0\rangle. \quad (3.17)$$

So, we have for the photon field scalar function the following expression

$$\Psi(\vec{r}, t) = \langle 0|\hat{\psi}(\vec{r})|\psi(t)\rangle, \quad (3.18)$$

coinciding in its form with the customary expression for the field scalar function of any genuine particle in the matter.

We have also to remark once again, that physical meaning of the operators of the photon creation and annihilation seems to be needing in the reconsideration. It is associated with the revival of photons by absorption processes [see further]. More precisely, the physical sense of the operators of the photon creation and annihilation consists in the acquisition and emptying respectively of the quanta of the energy and the impulse. In the subsequent consideration, the operators of the photon creation and annihilation are used in the given sense.

The theoretical consideration of the structure of a quantised EM-field has been done in [15]. The fundamental result, obtained by Dirac, that the dynamical system, which consists of the ensemble of identical bosons is equivalent to the dynamical system, which consists of the ensemble of oscillators, was used in [15] to show, that the presence of the scalar charge function $\rho(\vec{r}, t)$, which was established in [23] and which is peer force scalar characteristic of an electromagnetic field along with vector force characteristics $\vec{E}(\vec{r}, t)$, $\vec{H}(\vec{r}, t)$ agrees with the charge neutrality of photons. The simplest analogue in its mathematical description in the physics of the condensed matter is the chain of bosonic (spin S = 1) carbon atoms in organic conductors like to *trans*-polyacetylene. It has been shown, that neutral photons are topological relativistic solitons with nonzero spin value, which is equal to $\frac{1}{2}$ instead of the prevalent viewpoint, that the photons possess by spin $S = 1$. It was argued, by the way, that the representation of photons being to be the result of the spin-charge separation effect in the "boson-atomic" structure of EM-field makes substantially more clear the nature of the corpuscular-wave dualism [15].

Let us remark, that the bosons in the structure of EM-field are considered in [15] being to be rest massless. However, all the conclusions are held also in the case, if the bosons in the structure of EM-field can have some rest mass.

The theoretical substantiation of the "boson-atomic" structure of EM-field seems to be significant and we will review the results concerning the theoretical description of the given model in [15], which are based in its turn on the analogy with the quantum 1D Fermi liquid model for the description of 1D correlated electronic systems, elaborated in [50, 51]. The simplest analogue in the physics of condensed matter of the system of interacting S = 1 bosons is, how it was indicated above, carbon. So, the model of linearly polarized EM-field to be the chain of bosons, which is like in its mathematical description to the chain of carbon atoms in *trans*-polyacetylene (t-PA), at that both in "atomic" and "electronic" structure seems to be natural. One-dimensionality of the task can be argued in the following way. Since for the description of EM-field instead of unobservable vector and scalar potentials the 4-vectors of electrical and/or magnetic field strengths can be used, then, to describe linearly polarized EM-field in Euclidian space R_3 it is sufficient to specify the propagation direction, that is the vector $\vec{k}$ and to define $\vec{E}$. Given vectors determine the plane, in which a frame of reference with z-axis along the propagation direction and orthogonal to it x-axis can be set. Taking into account the homogeneity of Minkowski space R_4 and homogeneity of free EM-field in it, free EM-field can be modelled by the set of noninteracting (or weak interacting) between themselves "boson-atomic" chains, similarly to those ones in many carbon-based polymer systems. What concerned the "atomic" structure, it was included the contribution of vacuum fluctuations, which presents in the oscillator task and which is absent in the case of the boson task. The presence of charge, being to be the scalar EM-field function, gives the possibility to model an "electronic" structure of an equivalent boson chain like to t-PA electronic structure, that is consisting of "σ-subsystem" and "π-subsystem". It becomes to be understandable, if to take into account, that the charge space distribution is directly connected with $\vec{E}$ space distribution. In other words, the presence of E_z-component will determine the appearance of EM-field charge "σ-subsystem", while E_x-component will determine the appearance of EM-field charge "π-subsystem", at that, like to t-PA, its distribution in the space R_3 will be twice degenerated. Given conclusion can be argued on the basis of the quaternion structure of EM-field in the following way. E_x-polar component by EM-field propagation every other half-period alters its sign, at the same time E_x-axial component does not alters its sign, which is equivalent to the appearance of alternating single-double interbosonic "π-bonds" in EM-field charge "π-subsystem", at that two configuration - single-double and double-single are topologically equivalent. From here the conclusion has been done in (15), that the interaction between equivalent to oscillators "bosonic atoms" can be described within the frames of 1D Fermi gas model in the zero-th order approximation or within the frames of 1D Fermi liquid model in the first order approximation. The mathematical description of the Fermi liquid model for EM-field charge distribution, given in [15] is the following. The consideration has been started from the Hamiltonian

$$\hat{\mathcal{H}}(u) = \hat{\mathcal{H}}_0(u) + \hat{\mathcal{H}}_{\pi,t}(u) + \hat{\mathcal{H}}_{\pi,u}(u). \tag{3.19}$$

Like to the work [61] the Born-Oppenheimer approximation was considered. The first term in (3.19) is

$$\hat{\mathcal{H}}_0(u) = \sum_m \sum_s (E_m^k \hat{a}^+_{m,s}\hat{a}_{m,s} + K u_m^2 \hat{a}^+_{m,s}\hat{a}_{m,s}), \tag{3.20}$$

it is the operator of the kinetic energy of the "boson atomic" motion (the first term), and the operator of the σ-bonding energy (the second term), K is effective σ-bonds spring constant, u_m is configuration coordinate for m-th "boson atom", which corresponds to translation of m-th "boson atom" along the symmetry axis z of the chain, $m = \overline{1, N}$, N is the number of "boson atoms" in the chain, $\hat{a}^+_{m,s}$, $\hat{a}_{m,s}$ are creation and annihilation operators of the creation or annihilation of the quasiparticle with the spin projection s on the m-th chain site in "σ-subsystem". The second term in (3.19) is

$$\hat{\mathcal{H}}_{\pi,t}(u) = \sum_m \sum_s [t_0(\hat{c}^+_{m+1,s}\hat{c}_{m,s} + \hat{c}^+_{m,s}\hat{c}_{m+1,s})]. \tag{3.21}$$

It is the resonance interaction (hopping interaction in tight-binding model approximation) of quasi-particles in "π-subsystem" of all charge system, which is considered to be Fermi liquid, and in which the only constant term in Taylor series expansion of resonance integral about the dimerized state is taking into account. Here $\hat{c}^+_{m,s}$, $\hat{c}_{m,s}$ are creation and annihilation operators of the creation or annihilation of the quasipartile with spin projection s on the m-th chain site in "π-subsystem". The third term in (3.19) is

$$\begin{aligned}\hat{\mathcal{H}}_{\pi,u}(u) = \sum_m \sum_s [(-1)^m 2\alpha_1 u(\hat{c}^+_{m+1,s}\hat{c}_{m,s}+ \\ \hat{c}^+_{m,s}\hat{c}_{m+1,s}) + (-1)^m 2\alpha_2 u \hat{c}^+_{m,s}\hat{c}^+_{m+1,s}\hat{c}_{m+1,s}\hat{c}_{m,s}].\end{aligned} \tag{3.22}$$

It represents correspondingly the terms, which are proportional to linear terms in Taylor series expansion about the dimerized state of the resonance interaction of quasiparticles in "π-subsystem" of the charge system and the potential energy of the pairwise interaction of quasiparticles in "π-subsystem" between themselves. It is taken into account, that in Born-Oppenheimer approximation in a perfectly dimerized chain the coordinates $\{u_m\}$, $m = \overline{1, N}$, can be represented in the form $\{u_m\} = \{(-1)^m u\}$, where u is the displacement amplitude, corresponding to the minimum of the ground state energy [61]. In result of solving of the task formulated with Hamiltonian (3.19) two values for the energy of quasiparticles were obtained, indicating on the possibility of the formation of the quasiparticles in c-band and v-band of two kinds. They are

$$E_k^{(c)}(u) = \frac{\mathcal{Q}^2\Delta_k^2 - \epsilon_k^2}{\sqrt{\epsilon_k^2 + \mathcal{Q}^2\Delta_k^2}}, \quad E_k^{(v)}(u) = \frac{\epsilon_k^2 - \mathcal{Q}^2\Delta_k^2}{\sqrt{\epsilon_k^2 + \mathcal{Q}^2\Delta_k^2}} \tag{3.23}$$

and

$$E_k^{(c)}(u) = \sqrt{\epsilon_k^2 + \mathcal{Q}^2\Delta_k^2}, \quad E_k^{(v)}(u) = -\sqrt{\epsilon_k^2 + \mathcal{Q}^2\Delta_k^2}, \tag{3.24}$$

where $\Delta_k = 4\alpha_1 u \sin ka$, $\epsilon_k = 2t_0 \cos ka$, the value for factor $\mathcal{Q}$ satysfies the equation

$$[1 + \frac{\alpha_2}{2\alpha_1}\sum_k\sum_s \frac{\mathcal{Q}\Delta_k \sin ka}{\sqrt{\epsilon_k^2 + \mathcal{Q}^2\Delta_k^2}}(n_{k,s}^{(c)} - n_{k,s}^{(v)})] = \mathcal{Q}, \tag{3.25}$$

where $n_{k,s}^{(c)}$ is the eigenvalue of the density operator of a quasiparticles' number in c-band, $n_{k,s}^{(v)}$ is the eigenvalue of the density operator of a quasiparticles' number in v-band. It is evident, that at $\mathcal{Q} = 1$ in (3.23), (3.24) the case, equivalent mathematically to SSH-model will be realized. It can be realized, consequently, if $\frac{\alpha_2}{\alpha_1}\sum_k\sum_s \frac{1}{2}\frac{\Delta_k}{\sqrt{\epsilon_k^2+\Delta_k^2}} \sin ka(n_{k,s}^{(c)} - n_{k,s}^{(v)})] \to 0$, which, in its turn, is realized, if $\alpha_2 \to 0$. It was the reason, that the opposite case, when $|\frac{\alpha_2}{\alpha_1}\sum_k\sum_s \frac{1}{2}\frac{\Delta_k}{\sqrt{\epsilon_k^2+\Delta_k^2}} \sin ka(n_{k,s}^{(c)} - n_{k,s}^{(v)})]| \gg 1$ was considered. It was done by passing onto continuum limit, in which $\sum_k\sum_s \to 2\frac{Na}{\pi}\int_0^{\frac{\pi}{2a}}$, and assuming $n_{k,s}^{(v)} = 1$, $n_{k,s}^{(c)} = 0$. Then the following integral equation for the determination of the factor $\mathcal{Q}$ was obtained

$$\frac{2Nua\alpha_2}{\alpha_1\pi t_0}\int_0^{\frac{\pi}{2a}} \frac{\sin^2 ka}{\sqrt{1 - \sin^2 ka[1 - (\frac{2u\mathcal{Q}}{t_0})^2]}}dk = 1. \tag{3.26}$$

In the case $|\frac{2u\mathcal{Q}}{t_0}| < 1$ and in the case $|\frac{2u\mathcal{Q}}{t_0}| > 1$ $\mathcal{Q}$ was evaluated from the relation (3.26) appoximately. In the case $\frac{2u\mathcal{Q}}{t_0} = 1$ the parameter $\mathcal{Q}$ was calculated exactly. The quasiparticles of the second kind at $\mathcal{Q} = 1$ are quite similar in its mathematical description to the quasiparticles, that are those ones, which were obtained in [61]. It was found, that SSH-like solution is inapplicable for the description of standard processes, passing near equilibrium state by any parameters. The quasiparticles, described by SSH-like solution, can be created the only in a strongly nonequilibrium state with the inverse population of the levels in c- and v-bands. At the same time, the first solution can be realized both in near equilibrium and in the strongly nonequilibrium states of the "π-subsystem" of a boson-"atomic" chain, which is considered to be quantum Fermi liquid. The continuum limit for the ground state energy of boson-"atomic" chain with SSH-like quasiparticles will coincide in its mathematical form with the known solution [61], if to replace $\Delta_k\mathcal{Q} \to \Delta_k$. The calculation of the ground state energy $E_0^{[u]}(u)$ of the boson-"atomic" chain with quasiparticles' branch, which is stable near an equilibrium has been done. It was taken into account, that in the ground state $n_{k,s}^c = 0$, $n_{k,s}^v = 1$. Then, in the continuum limit

$$E_0^{[u]}(u) = -\frac{2Na}{\pi}\int_0^{\frac{\pi}{2a}} \frac{(\mathcal{Q}\Delta_k)^2 - \epsilon_k^2}{\sqrt{(\mathcal{Q}\Delta_k)^2 + \epsilon_k^2}}dk + 2NKu^2, \tag{3.27}$$

further, the calculation of the integral, using the complete elliptic integral of the first kind $F(\frac{\pi}{2}, 1-z^2)$ and the complete elliptic integral of the second kind $E(\frac{\pi}{2}, 1-z^2)$, has resulted

$$\begin{aligned} E_0^{[u]}(u) = \frac{4Nt_0}{\pi}\{F(\frac{\pi}{2}, 1-z^2)+ \\ \frac{1+z^2}{1-z^2}[E(\frac{\pi}{2}, 1-z^2) - F(\frac{\pi}{2}, 1-z^2)]\} + 2NKu^2, \end{aligned} \tag{3.28}$$

where $z^2 = \frac{2\mathcal{Q}\alpha_1 u}{t_0}$. The approximation of (3.28) at $z \ll 1$ gives

$$\begin{aligned} E_0^{[u]}(u) = N\{\frac{4t_0}{\pi} - \frac{6}{\pi}\ln\frac{2t_0}{\mathcal{Q}\alpha_1 u}\frac{4(\mathcal{Q}\alpha_1)^2u^2}{t_0}+ \\ \frac{28(\mathcal{Q}\alpha_1)^2u^2}{\pi t_0} + ...\} + 2NKu^2. \end{aligned} \tag{3.29}$$

It is seen from (3.29), that the energy of quasiparticles, described by the first solution, has the form of Coleman-Weinberg potential with two minima at the values of dimerization coordinates u_0 and $-u_0$ like to the energy of quasiparticles, described by SSH-solution for t-PA [61].

Therefore, all qualitative conclusions of the model proposed in [61] are holding in the Fermi-liquid consideration of "π-subsystem" of the chain (instead of Fermi-gas consideration) for the quasiparticles, corresponding to the first-branch-solution. It is evident, that the mechanism of the phenomenon of the spin-charge separation in 1D Fermi-liquid is the soliton mechanism, analogous to the mechanism proposed by Jackiw and Rebbi [53] on the basis of field theory positions and to the mechanism proposed by Luther and Emery [52], but it is quite different from Anderson spinon-holon mechanism [54].

Thus, the results obtained allowed to propose the reasonable explanation of the existence in the fields with charges of chargeless particles - solitons with nonzero spin value, which in the case of EM-field is equal to $\frac{1}{2}$ instead of the prevalent viewpoint, that photons possess by spin $S = 1$. The photons in quantized EM-field are main excitations in the spin S = 1 boson-"atomic" EM-field structure, like mathematically to the well known spin S = 1 boson matter structure - carbon atomic backbone structure in chains of many conjugated polymers. The photons have the two kind nature. The photons of the first kind represent themselves neutral EM-solitons of SSH-soliton family. They are main excitations in so-called "undoped " structure of EM-field, including free EM-field in the vacuum. Naturally, they have nonzero size, that is they cannot be considered to be point objects in full correspondence with the evaluation of the photon size, presented in the given paper [see below]. It seems to be evident, that like to Fermi-gas SSH-model, the main excitations in the "doped" boson-"atomic" structure of EM-field will be charged spinless EM-solitons, which also can be referred to the SSH-soliton family. It is reasonable to suggest, that "doping" can be effective in the medium like to rain-clouds, although detailed mechanism has to be additionally studied. The representation of photons to be the result of the spin-charge separation effect and their assignment with main excitations in the ground state of "π-subsystem" of the field charge in the boson-"atomic" EM-field structure - chargeless spin $\frac{1}{2}$ topological solitons - makes substantially more clear the nature of corpuscular-wave dualism, how it was mentioned above.

In fact, it is given in the paper [15] the new physically clear interpretation of the corpuscular-wave dualism. It is explained by the complex structure of EM-field. Really, since the quantized EM-field represents itself according to the model proposed the discrete boson-"atomic" structure like to an atomic structure existing in condensed matter, the origin of waves in the given structure is determined by the mechanism, being to be quite analogous to the formation of Bloch waves in the solid state of condensed matter. They are harmonic trigonometric functions for Maxwellian EM-field, which determine their wave character. At the same time, there are simultaneously the corpuscles, propagating along EM-field boson-"atomic" chains, that is, chargeless spin 1/2 topological relativistic solitons - photons, which are formed in usual conditions (or spinless charged solitons in so-called "doped" EM-field structure). In other words, EM-field boson-"atomic" chains is the medium for the photons' propagation.

It becomes now to be understandable, that the display of the corpuscular or the wave nature of EM-field will be dependent on experimental conditions.

The experimental results on the interference and diffracion of light reported in [14] seem to be the excellent confirmation for the given conclusion. The observation of the only corpuscular properties at a low light intensity is easily explained by a rectlinear propagation of photons, the size of which is naturally not exceeding the size of the silver embryo, which was found rather small. At the same time, the boson-atomic density is rather low in interslit space at a low light intensity and the formation of Bloch-like waves do not take place. In fact, the given experiment indicates that there is the threshold in the EM-field boson-atomic density for the formation of Bloch-like waves and correspondingly there is the threshold in light intensities. Consequently, the wave properties of the light can be observed the only by the intensities, exceeding the given threshold. In other words, owing to the ability of a quantum Fermi liquid (like to any liquid) to spreading, the infill of all interslit space takes place, however the concentration of field bosons has to be sufficient to realize the interslit space infill. It is interesting to remark, that the representation of EM-field to be a quantum liquid is well agree with the classical representation of the propagation process of the light through small apertures, in which the apertures are postulated being to be new light point sources. It is quite similar to spreading of any liquid through small apertures by the presence of the pressure like to spreading of a eau-de-Cologne from a bottle of eau-de-Cologne with a pulverizer in hairdressing saloons [the presence of a light pressure is taken into account in the given comparison].

Therefore, the experimental results described in [14] seem to be the most striking argument in the favour of the quantum Fermi liquid model of EM-field, proposed in [15].

Let us reproduce the additional experimental confirmations of the model proposed, which are given in [15]. The very strong argument in favour of the model proposed is the well known experimentally observed phenomenon of an electron-positron annihilation. It is well theoretically described, see, for example [58], and experimentally confirmed that by the direct annihilation of an electron-positron pair two photons are produced. At the same time, the explanation for the case of the relative velocity of annihilating particles near to zero, how can be produced from two particles with spin value 1/2 also two particles, however with spin value 1, is in fact absent. It is evident, that the boson model presented explains the given disagreement between experimental data on an electron-positron annihilation and the theoretical viewpoint on the photon to be the spin-1 particle in a natural way - from two particles with the spin values 1/2, that is from a electron-positron pair can be produced two photons the only with the spin values 1/2.

The second argument is the existence of the dependence of a resonance microwave absorption rate on the spin value of absorbing centers, which was found in the electron spin resonance (ESR) spectroscopy for the first time in [59, 60]. It was established, that spin 1-centers absorb the microwave power with the rate exceeding the absorption rate by spin 1/2-centers precisely two times more. It follows from the given result the reasonable suggestion, that if the photons were possessing by spin 1 they couldn't be absorbed in ESR conditions by the centers with the spin value 1/2 (like to the absence of any ESR-absorption by the centers with the zeroth spin value).

The third argument is the aforedescribed peculiarities of interactions of photons with Higgs bosons within the frames of the Standard Model in comparison with qualitatively quite different interactions of Higgs bosons with boson messengers Z and W of the weak interaction and the coincidence of the dimensionality of the 2D-spinor space, corresponding to the description of the particles with spin value, equaled to 1/2 (instead of 3D-vector space) with the dimensionality equaled to 2 aforeindicated, which is accepted for the description of photons within the frames of the Standard Model.

It was remarked in [15], that the model proposed is in fact the development of an idea of multiphoton "molecules". The idea of multiphoton "molecules" arose at the earliest stage of the quantum physics era around 1910, and it belongs to Debye [55]. It is interesting, that the given concept has remained a long time being to be unclaimed and the only relatively recently, on the frontier of the millennia, in

2000 it was renewed. In particular, the complete radiation formula from the corpuscular concept of the photon "molecules" has been obtained in [57], indicating on the correctness of the photon "molecules" model. The authors of [57] have obtained the complete radiation formula on the base of Debye photon "molecules" idea, using the description of multiphoton states in multiphoton "molecules", which was proposed in [56]: light of definite direction and frequency ν presents itself in units "molecules" of 0, 1, 2, ..., n, ...photons, with energy $nh\nu$, that is, with the zeroth binding energy, and they contribute independently to the energy density. The authors of [57] accentuate, that the given assumption is rational, it is in the spirit of the atomistic Democritean viewpoint, and it means that all the photons of the same frequency are identical.

Especially interesting, that the boson chain description of EM-field, the photons in which, being to be noninteracting between themselves topological solitons in the atomistic 1D-chain structure of the linearly polarized light, can really be represented by 1D "molecules" of 0, 1, 2, ..., n, ...quasiparticles, with the total energy $nh\nu$, that is, with the zeroth binding energy, in the full accordance with the model, proposed by [55, 56, 57].

The quantum Fermi liquid model of EM-field, proposed in [15] allows to give the theoretical evaluation of the photon size. The evaluation can be obtained by the comparison with Su-Schrieffer-Heeger theory of organic conductors [61]. In other words, it is reasonably to suggest, that photons and topological defects in Su-Schrieffer-Heeger theory have the comparable sizes. The theoretical value of the coherence length for topological solitons in *trans*-polyacetylene is $7a$ [a is interatomic spacing in *trans*-polyacetylene carbon chain], and it is the low boundary in the range $7a-11a$, obtained for the soliton coherence length from experiments. Therefore, the evaluation of the photon size is $7a'-11a'$, where a' is a distance between field bosons in a light ray. It is unknown at present, however the strong interaction of photons with atomic systems allows to suggest that a' is comparable with interatomic distances in condensed matter systems and, consequently, the size of a photon is of the nanoscale range.

The following experiment can give the evaluation of the upper boundary for the the size of a photon. It is followed from the work [59], that the Rabi frequency of P6 centers in Si is 5.05×10^6 rad s^{-1} [by converting to 100 mW instead of 40 mW used, which is possible if to take into account the linear dependence of the Rabi frequency on the magnetic component of a microwave field]. The photon flux 10^{22} s^{-1} corresponds to the power in 100 mW at the microwave frequency 10^{10} Hz. During the half period of Rabi oscillations the absorption of photons takes place. The evaluation of their number in the sample with the volume 1 cm^3, placed in the cavity so, in order all the flux was coming through the sample surface and filling the sample, gives the value 6.2×10^{15} photons cm^{-3}. Hence, the interphoton distance is equal to 540 nm. It is clear, that the photon size is smaller than the given value [since the photons in all known stationary spectroscopy experiments can be considered to be noninteracting between themselves]. It means, that really the suggestion in [14] on the size of photons being to be comparable with the macrosize of an interslit distance in interference experiments is erroneous.

We have also to remark that all existing quantum optics theories do not explain correctly the phenomenon of the interference, in particular, the classical experiment of Young with two slits. According to [16], the appearance of the interference in Young experiment depends on the coherence degree of two beams of light only and do not depends on their intensity in contradiction with the results described in [14]. All the more, the attempt to consider the propagation of a single photon through two slits simultaneously undertaken by some authors seems to be the grossest blunder.

We have to indicate, that there is existing the other concept of the photon origin, according to which the photon is rapid oscillation of a segment of superstring [62, 63]. At the same time the base of boson model above reviewed, which leads, in particular, to the existence of electrically neutral photons with spin values 1/2 has reliable experimental confirmation by positron annihilation. Morereover, the Fermi liquid essence of EM-field is very well agreeds with light interference experiments.

4 Physics of Photon Absorption

After recovering the status of a photon in the electrodynamics to be the genuine particle and introducing the some clarity into its geometry and spin-charge characteristics, it seems to be significant to solve the task concerning the physical essence of the photon absorption process itself in the matter. The given task seems to be not trivial, and it was in fact formulated by Dirac already in 1927, however, it is not solved up to now, although the classical description of the absorption process of the energy of EM-field is well elaborated. Dirac in the work [7] writes, that the photon possesses by the strange peculiarity, it, seemingly, discontinues to exist, when it is located in one of its stationary states, just, in the zeroth state, in which its energy and its impulse are equal to zero. The absorption of a light quantum, according to Dirac suggestion, is equivalent to a light quantum jump in the zeroth state, and its emission is its jump from the zeroth state in a some new state, where the photon existence is physically evident, so, it seems that it was recreated. The given Dirac's comment can be really considered being to be the formulation of the task of quantum absorption process, at that Dirac remains seemingly the alternative - the discontinuity of a photon existence in the zeroth state, or its revival by some way in the given state. However, the words "We have to suggest, that there are in the zeroth state infinitely many of the light quanta", - indicate that Dirac gives the preference to the photon revival variant, which he uses in the subsequent computations of the quantum absorption and emission process, at that, he deals by computations with a great but a finite number of photons. The given conclusion indicates on a very deep insight of Dirac in the field. Futher, we will represent the development of the given Dirac photon revival idea in the zeroth state and its experimental confirmation by modern spectroscopic studies.

There is also another aspect in the description of photon absorption and emission processes. It is the finite nonzeroth time of the interaction of photons with matter by their absorption and emission, which does not take into account both in classical and quantum electrodynamics. The attention was drawn on the given aspect also by Dirac [7]. Dirac has indicated, that for the correct description of the electrodynamic system the fact that forces propagate not instantaneous, but with the light velocity, has to be taken into consideration. Finite times of the interactions of EM-field with the matter have to be taken into account correctly by the studies of absorption, reflection and other processes of interactions of EM-field with the matter in all the stationary measurements. At the same time the Bloch equations are used both by quantum and classical descriptions of the given processes. The given equations take into consideration the relaxation of the only excited states by stationary processes. In other words the transition of absorbing centers (atoms, molecules and so on) into an excited state by the interaction with photons is postulated in implicit form to be instantaneous by all stationary optical and radiospectroscopy studies. At that, the level of stationary signals is considered to be determining by the interplay of the photon flux intensity and effectivity of the relaxation processes from the excited state. At the same time, quite another situation can be realized, in which the level of stationary signals is determined by the time of the transition in the excited state, which can be rather long. Moreover, characteristic times of of the transition in the excited state can even exceed the time of relaxation processes from the excited state.

Let us give the physical ground for the given conclusion. In the work [19] was developed a theory of Rabi oscillations in a periodical 1D chain of two-level quantum dots (QD) with tunneling coupling, exposed to quantum light. The role of interdot coupling and Rabi oscillations on each other was considered in details. The following conclusions have been done from the studies.

1.The interdot tunneling in the QD chain exposed to quantum light leads to the appearance of spatial modulation of Rabi oscillations and in the appearance of the phenomenon of Rabi waves propagation. It is shown, that Rabi waves can propagate if the light mode wave vector has nonzero component along the chain axis. Characteristics of the Rabi waves depend strongly on relations between parameter of electron-photon coupling, frequency deviation and transparency factors of potential barriers for both of levels of individual QDs.

2.Traveling Rabi wave represent the quantum state of QD chain dressed by radiation, that is, joined states of electron-hole (e-h) pair and photons. The qualitative distinction of these states from the similar states of single dressed atom is the space-time modulation of dressing parameter according to the traveling wave law. The propagation of traveling Rabi wave looks like supported by periodically inhomogeneous nonreciprocal effective media, whose refractive index is determined by electric field distribution. For the quantum description of the given Rabi oscillation propagation process the authors introduce the quasiparticles of a new type - rabitons, which can be considered being to be the generalization of Hopfield polaritons for the case of indirect quantum transitions.

3.Two traveling Rabi modes with different frequencies of Rabi oscillations corresponds to the given value of wave number. The range of Rabi oscillation frequencies is limited by the critical value, which is different for both of the modes. The QD chain is opaque in the regime of Rabi oscillation frequencies below the critical value. At the same time it is shown, that the critical frequencies and dispersion characteristics of Rabi modes depend on number of photons.

4.The formation of different types of Rabi wave packets was considered. It has been found, that they represent themselves arbitrary superpositions of four partial subpackets with different amplitudes, frequency shifts, and velocities of a motion. Two of subpackets correspond to the contribution of excited initial state and two others caused by the ground initial state contribution. It was established that Rabi wave packets transfer energy, inversion, quasimomentum, electron-electron, and electron-photon quantum correlations along the chain. The number of subpackets can be diminished in specific circumstances.

5.For the case of QD chain considered in the work cited, it is found, that Rabi oscillations qualitatively change the electron tunneling picture in the given chain. In contrast to the case of the absence of electron-photon coupling, the movement of initially ground state subpacket is governed by tunneling transparency of excited energy level and vice versa. Thus, Rabi oscillations can stimulate tunneling through low-energy level and suppress it through high-energy one.

6.It has been established, that Rabi wave packet movement along the QD chain alters the light statistics. Particularly, it was predicted for the QD chain, exposed to coherent light the drastic modification of the standard collapse-revival phenomenon: collapses and revivals appear in different areas of the chain space.

It seems especially significant the conclusion of the authors of [19], that the phenomenon of Rabi waves'formation can take place in a number of other distributed systems strongly coupled with electromagnetic field. For the example they indicate on the possibility of Rabi waves' formation in superconducting circuits based on Josephson junctions, which are currently the most experimentally advanced solid-state qubits. According to the opinion of the authors of [19] the qubit-qubit capacitance coupling in the chain of qubits placed inside a high-Q transmission-line resonator will be responsible for the Rabi waves propagation similar to described in the paper above cited. Let us also remark, that the theory elaborated in [19] can be considered to be the theory of quantum space radiative transport of a radiation field, in particular, a light field, by its interaction with matter.

We wish to draw attention, that the analysis of the results obtained in the work [19] allows to predict the additional new quantum phenomenon - the two stage process of a photon absorption, which can have rather long times, even more long than the relaxation times of the excited atomic states. So, in the first stage the rabiton formation takes place. The given process can be rather fast. The second stage is determined by a lifetime of rabitons, in which photons, being to be not absorbed coexist with absorbing matter excitons. Really, the state vector of the "QD-chain+light" system, that is, the state vector of the rabiton was represented in [19] by direct product of the eigenstates of isolated QDs and photon number states in the following form

$$|\Psi(t)\rangle = \sum_n \sum_p (A_{p,n}(t)|a_p, n\rangle + B_{p,n}(t)|b_p, n\rangle), \tag{4.1}$$

where $|b_p, n\rangle = |b_p\rangle \otimes |n\rangle$, $|a_p, n\rangle = |a_p\rangle \otimes |n\rangle$, in which $|n\rangle$ is the light Fock state with n photons, $|a_p\rangle$, $|b_p\rangle$ are one-electron orbital wave-functions on the p-th QD in the excited and ground states respectively, $B_{p,n}$, $A_{p,n}$ are the probability amplitudes, $p \in N$.

The probability amplitudes are determined from the following equations

$$\frac{\partial A_{p,n}}{\partial t} = -\frac{i\omega_0}{2}A_{p,n} + i\xi_1(A_{p-1,n} + A_{p+1,n}) \\ - ig\sqrt{n+1}B_{p,n+1}e^{i(kpa-\omega t)} - i\Delta\omega B_{p,n}\sum_m A_{p,m}B^*_{p,m}, \quad (4.2)$$

$$\frac{\partial B_{p,n+1}}{\partial t} = \frac{i\omega_0}{2}B_{p,n+1} + i\xi_2(B_{p-1,n+1} + B_{p+1,n+1}) \\ - ig\sqrt{n+1}A_{p,n}e^{-i(kpa-\omega t)} - i\Delta\omega A_{p,n+1}\sum_m A^*_{p,m}B_{p,m}, \quad (4.3)$$

where

$$\Delta\omega = \frac{4\pi}{\hbar V}\mu(\widetilde{\underline{N}}\mu) \quad (4.4)$$

is the local-field induced depolarization shift, $\underline{N}$ in which is the depolarization tensor, $k = (\omega/c)\cos\alpha$ is the axial wave number, α denotes the angle between the light propagation direction and QD-chain, ω is angular frequency, $\xi_{1;2}$ are the electron tunneling frequencies for the excited (ξ_1) and ground (ξ_2) states of the QDs, $g = (\vec{\mu}\vec{\mathfrak{E}})/\hbar$ is the interaction constant, $\vec{\mu}$ is the QD dipole moment, $\vec{\mathfrak{E}} = \sqrt{2\pi\hbar\omega/V_0}\vec{e}$, V_0 is the normalizing volume, $\vec{e}$ is the unit polarization vector. Obtaining the given equations it was taken into account that the interaction can cause the transitions between the states $|a_p, n\rangle$, $|b_p, n+1\rangle$ only. It is seen from Eqs.(4.2)–(4.3), that two competitive mechanisms manifest themselves additionally to the ordinary Jaynes-Cummings dynamics: the local-field induced nonlinearity and quantum diffusion being to be the consequence of the interdot tunneling.

It seems to be substantial for the practical applications, that the given state is quantum coherent state. It also significant, that photons in the given bound state are moving with rather small velocities in comparison with c, that is, with the light velocity in vacuum. The extrapolation of the rabiton velocity to zero means that photon can exist in the state with the zeroth energy and zeroth impulse in the full correspondence with the Dirac guess. In fact, pinning of photons by absorbing centers is taking place. It is substantial to clarify, which characteristics remain for the rest zero mass photons in the given pinned state. It is spin, which in correspondence with results of [23] is the most fundamental characteristic of quantum states. It is reazonable to suggeste that the characteristic for topological solitons of SSH-family shape is also retained.

We wish also to draw attention that the creation and annihilation operators used in the quantum field theory and in the quantum electrodynamics in particular operate with a creation (annihilation) of an energy and an impulse and they are not concerned the spin of photons. According to aforegoing remark, the content of the given operators (at least in an application to photons) can by slighly modified. They transfer photons from pinned states and into the pinned states correspondingly without changes in the spin state. The agreement of quantum field calculations, which do not touch the spin of photons with experiments seems to be the strong argument for the given conclusion.

We have to remark that the existence of pinned photons in condensed matter does not contradict the special relativity theory, since according to it the photons have the velocity c in any inertial system being to be propagated in vacuum.

Understanding of the physics of absorption processes with a rabiton formation allows to predict the spectroscopiic experiments in which the signal level for a stationary state will be dependent on the the times of the transfer of a system of absorbing centers into excited state, moreover, to measure the given times. If the the times of the transfer of a system of absorbing centers into an excited state are more long in comparison with at least one from relaxation times, which are responsible for the transfer from an excited state, than the signal will have unsaturating behavior in dependence on a radiation power, whereas its maximum will be registered in a phase value being to be shifted on a some angle with regard to a reference signal by the modulation method of an absorption detection, if the modulation frequency is near to the reverce value of the time of the transfer of a system of absorbing centers into excited state. The modulation method of an absorption detection is used in the magnetic resonance spectroscopy, although it is applied sometimes in the optical spectroscopy too.

The corresponding time can be measured by the method, analogous to the method, which is very good developed in photoconductivity studies [64] in semiconductors. Let us give the brief description of the given method in the application to magnetic resonance experiments. The static magnetic field modulation can be replaced in the linear approximation by the modulation of the microwave field. Then its intensity I(t) can be described by the relation

$$I(t) = I_a(1 - \cos\omega_m t), \tag{4.5}$$

where ω_m is the value of the modulation frequency. The phenomenological equation for the linear responce $A(t)$ of the system of absorbinng centers on the given modulation is

$$\frac{dA(t)}{dt} = \alpha I_a(1 - \cos\omega_m t) - \frac{A(t)}{\tau_g}, \tag{4.6}$$

where τ_g is the characteristic time of the growth of the responce signal, α is the value characterizing the electron-photon effective interaction, suggested to be constant. The solution of the given equation is

$$\begin{aligned} &A(t) = \alpha I_a\tau_g + \alpha I_a\tau_g\frac{1}{1+\omega_m^2\tau_g^2}\times \\ &(\tau_g\omega\sin\omega_m t + \cos\omega_m t) + A_0\exp(-\frac{t}{\tau_g}) \end{aligned}, \tag{4.7}$$

where A_0 is the constant of integration. Taking into account the initial condition $A(t) = 0$ at $t = 0$, we will have

$$\begin{aligned} &A(t) = \alpha I_a\tau_g[1 - \frac{2+\omega_m^2\tau_g^2}{1+\omega_m^2\tau_g^2}]\exp(-\frac{t}{\tau_g}) + \\ &\frac{\alpha I_a\tau_g}{1+\omega_m^2\tau_g^2}(\tau_g\omega\sin\omega_m t + \cos\omega_m t) \end{aligned}. \tag{4.8}$$

Then, in the stationary conditions we obtain

$$\begin{aligned} &A_{st}(t) = \frac{\alpha I_a\tau_g}{1+\omega_m^2\tau_g^2}(\tau_g\omega\sin\omega_m t \\ &+ \cos[\omega_m t - \arctan(\omega_m\tau_g)] \end{aligned}. \tag{4.9}$$

Therefore, for the angle ϑ between the maximum of the registered absorption signal and reference signal by the sinchronous detection we will have the expression

$$\vartheta = \arctan(\omega_m\tau_g); \tag{4.10}$$

which allows to determine τ_g.

We have analysed the literature and have found the corresponding results. It has been reported in the work [65], that the paramagnetic absorption changes linearly in dependence on the magnetic component of a microwave power in the boron implanted (425-150 keV) diamond films (Figure 9 in [65]). At the same time the EPR signal recorded in these films and in the nickel-implanted diamond single crystals (335 MeV, $5 \times 10^{14} cm^{-2}$) [65, 66] has an additional angle in respect to the phase of the hf-modulation field (Figure 15 in [65]). In the diamond films this angle is anisotropic and changes within 20 degrees when samples are rotated in a static magnetic field. At the same time, in the nickel-implanted diamond single crystals the additional phase angle was found to be isotropic. It is characteristic, that the kinetics of the intensity of an EPR signal recorded in phase $I(H_1)$ and in quadrature $I_q(H_1)$ with the hf-modulation field is the same, that is, linear in the boron-implanted 425-150 keV films (Figure 9 in [65]) and superlinear in the nickel-implanted diamond single crystals (Figure 7 in [66]). On the one hand, this fact is the evidence that the EPR lines recorded both in phase and in quadrature with the hf-modulation field correspond to the same PCs, thereby confirming again the appearance of an additional phase angle in an EPR signal recorded with the use of hf-modulation. On the other hand, this points to the fact that in the case considered the mechanism of the formation of paramagnetic absorption, which is responsible for the EPR signal recorded in quadrature with the hf-modulation field, differs from the known mechanism. Usually, the EPR signal recorded in quadrature with the hf-modulation field corresponds to PCs having long times of paramaguetic relaxation and differing in their nature from PCs, being to be responsible for the EPR signal recorded in phase [71]. So, it was found the direct proof, that the amplitude and phase of the stationary EPR absorption in the samples above indicated are determined by the times of the interaction of absorbing centers with microwave range photons, indicating in its turn on the quantum character of EPR absorption in the given samples, studied in [65]. The value of the time of transfer in excited state for the angle ϑ = 20 degrees is $\tau_g = 5.8 \times 10^{-7} s$. It is direct indication that in the samples studied in (65), (66) the longlived coherent states are realized. The additional argument of the quantum character of EPR absorption in the samples, studied in [65, 66] is the observation of super-Lorentz shape of the EPR absorption lines. Super-Lorentz shape seems to be appearing being the consequence of quantum character of the relaxation processes, when instead of exponential relaxation, leading to Lorentz shape of the EPR absorption lines, the so-called collapse and revival discrete sequence takes place.

The relation of the transient ESR free induction envelope decay with characteristic time (T_2) to the electron spin resonance line shape is well known. It can be obtained mathematically through a Fourier transform, at that, the linewidth value is detemined by the time (T_2). Any Fourier transform seems to be correct in the case, when the decay function f(t) and the spectral function $f(\omega)$ satisfy to the conditions of the applicability of the Fourier transform. Let us remember, that they are the following: the decay function f(t) has to be summed up, $f(t) \in L_1(-\infty, +\infty)$, the spectral function $f(\omega)$ has to be bounded, uniformly continuous function, and $f(\omega) \to 0$ if $|\omega| \to \infty$. It is clear, that the Fourier analysis is correct in the case of usual spectroscopic transitions, the decay time in which is determined by ESR free induction decay being to be the result of the spin-spin and spin-lattice relaxation mechanisms, leading to the transition of the absorbing system from an excited into ground state. Substantially, that the relaxed spin subsystem is independent in the given case on the photon subsystem [mathematically the state of absorbing centers is not described by direct product of photon coherent state and PC-state]. However, in the case above considered the decay of the ground state population takes place and it is determined by the interaction with the photon subsystem, that is, it is realised by quantum Rabi oscillations discrete process and its connection with the shape of the EPR absorption lines becomes nontrivial, owing to its discreteness both in the time and in the space [19]. Qualitative aspect of the description of the line shape can be obtained by space averaging of propagating quantum Rabi oscillations. Then, we can restrict themselves to the consideration of the effect expected within the frames of the Jaynes-Cummings model (JCM) [68].

Let us touch on Jaynes-Cummings model [68] in some details. Central role in JCM plays the sum with infinite summation limit, which represents on a scale [-1,1] the degree of excitation of two-level system resulting of interaction between the atom dipole or spin and single mode quantized EM-field. It is

$$\langle \hat{\sigma}^z(t) \rangle = -\exp[-|\alpha|^2] \sum_{n=1}^{\infty} \frac{|\alpha|^{2n}}{n!} \cos 2g\sqrt{\overline{n}}t, \tag{4.11}$$

where $|\alpha\rangle$ is fully coherent state of the field, taking place at $t = 0$, at that $|\alpha|^2 = \overline{n}$, that is, it is the average number of photons in the field, g is coupling constant between field and atom (spin). The sum in (4.11) cannot be expressed exactly in analytical form. For very short times and very large $\overline{n}$ behavior of $\langle\hat{\sigma}^z(t)\rangle$ is determined by $\cos 2g\sqrt{\overline{n}}t$. Cummings [69] has shown, that by resonance and for intermediate time t values the cosine Rabi oscillation damp quickly (so-called collapse takes place). Given damping can be described by Gaussian envelope

$$\exp[-\frac{1}{2}(gt)^2]. \tag{4.12}$$

It is substantial, that in the given approximation it not depends on field intensity unlike to the semi-classical Rabi oscillation damping process and it is determined entirely the only by coupling constant g.

The authors of the work [70] have found, that JCM contains so-called revival process with revival time t_r, given by the expression

$$t_r = \frac{\pi}{g^2}\sqrt{\Delta^2 + 4g^2\overline{n}}, \tag{4.13}$$

where Δ is deviation of field mode frequency from resonance value. Revival process takes place at all time values, satisfying the relation $t = kt_r,\ k \in N$. It is seen from (4.13), that revival time depends on $\overline{n}$ and it is proportional to oscillating field amplitude at $\Delta = 0$ like to the dependence of Rabi frequency on the magnetic component of microwave field by transient ESR spectroscopy by semiclassical consideration.

The authors of the work [70] have found an improvement on Cummings's collapse function [69] for the same intermediate range of times, depending on Δ and with nonlinear dependence on $\overline{n}$. They have found also the following approximation of the sum (4.11)

$$\begin{aligned}\langle\hat{\sigma}^z(t)\rangle \simeq \frac{\Delta^2}{\Omega^2} + \\ \frac{4\lambda^2\overline{n}}{\Delta^2}[1 + 16\frac{g^8\overline{n}^2t^2}{\Omega^6}]^{-\frac{1}{4}}\exp[-\varphi(t)]\cos\Phi(t),\end{aligned} \tag{4.14}$$

where

$$\varphi(t) = 2\overline{n}\sin^2[\frac{g^2t}{\Omega}][1 + 16\frac{g^8\overline{n}^2t^2}{\Omega^6}]^{-1} \tag{4.15}$$

and

$$\Phi(t) = \Omega t + \overline{n}\sin^2[\frac{g^2t}{\Omega}] - 2\frac{g^2t}{\Omega} - \frac{1}{2}\arctan[\frac{4g^4\overline{n}t}{\Omega^3}], \tag{4.16}$$

where $\Omega = \Delta^2 + 4\overline{n}g^2$. The value of the time t is considered being to be not so large, in order to satisfy the condition of the not strong overlap of neighboring revivals.

It is seen from (4.14) - (4.16), that in dependence on time segment choosing for the Fourier transform, and pulse sequence method used the quite different results can be obtained, in particular, with exponent degree n, characterising the envelope of decay process, equaled to n = 0, 1, 2 and intermediate. At n = 0 the only Rabi oscillations will be observed before any signs of decay. At n = 1 the Fourier transform will lead to the Lorentz shape of ESR lines. At n = 2, the shape will be Gaussian. Strongly speaking, the Fourier transform is inapplicable to the time discrete function $f_g(t)$, describing the decay of the ground state population, on the restricted time segment [the condition $f(t) \in L_1(-\infty, +\infty)$ has to be fullfilled]. At the same time, the envelope of decay process taking into account all the revival groups in JCM is described by the expression [70]

$$B(t) = \frac{[1 + 16g^8\overline{n}^2t^2}{\Omega^6}]^{-\frac{1}{4}}, \tag{4.17}$$

By using of the given function the all condititions of the application of the Fourier transform will be fullfilled. It leads however to quite another shape of stationary registered ESR lines. It will be super-Lorentzian, and it allows to explain qualitatively the super-Lorentzian shape observed in natural diamond samples of type Ia and IIa implanted with high energy ions of copper (63 MeV), neon (26.7 MeV), and nickel (335 MeV) along the $\langle 111 \rangle$, $\langle 100 \rangle$ and $\langle 110 \rangle$ crystallographic directions, [65, 66, 67]. It is in agreement with the explanation of the possibility to observe super-Lorentz shape in stationary ESR studies in the principle, given in (65) on the base of Kubo-Tomita theory, although the physical origin of the given possibility, that is the concrete physical mechanism was remained in [65] being rather vague.

The similar very interesting results, concerning phase angle, were reported in the paper [72]. The authors write: "A complication in the measuring process has been observed. It is related to variations in the signal phase that may develop through the measuring process. The reference AC phase of the lock-in- detector (LID) is adjusted for usual EPR measurements to yield the optimum paramagnetic resonance signal. However in case of the microwave dissipation observed in anisotropic superconductors this adjustment turns out to be not appropriate. Variations in the signal phase were observed when varying the magnitude of the variables involved (DC magnetic field, temperature, sample orientation and others). This effect necessitates a procedure where the lock-in detector phase has to be adjusted, throughout the measuring process, to be in-phase with the AC phase. To overcome this problem, conducted during the measuring process, the measurements were performed in steps of the variables involved, and at each step the lock-in detector phase had to be adjusted accordingly. This procedure results in an extremely cumbersome measurement, where the possibilities offered by the modern EPR Bruker spectrometer ELEXSYS E500 are extremely useful. A feature of this spectrometer is its possibility to measure the signal intensity in steps of two variables. It allows obtaining the measured signal intensity at each step, where the lock-in phase is varied from zero to 180 degrees. Repeating the measurement, by changing, in steps, the magnitude of the variable involved (magnetic field, temperature, angle of the oriented crystal) gives the measured signal intensity being to be the function of the variable at the full 180 degrees range of the lock-in phase. Then the measurements were analyzed using a proper computer program". It allowed to authors to obtain two curves, the measured signal amplitude, and the corresponding signal phase, being to be the function of the corresponding variable involved (DC magnetic field, AC magnetic field, sample orientation angle and temperature). Thus, the actual calculated signal was derived from the measured signal amplitude and its corresponding signal phase.

$Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystal was studied, zero field cooled to 4K with the DC magnetic field applied parallel to the a-b plane. The measured signal amplitude exhibits two maxima followed by an exponential decay towards zero at high fields. The signal phase is close to zero at low fields and drops steeply towards -180 degrees at high fields. It indicates that the signal is in phase and out of phase with the AC field at low and high fields, respectively. The deviations of the phase shift, that is deviations ± 20 from 0 at low fields and from 180 at high fields have been found, however they have not been investigated so far and need according to the opinion of authors in further attention. The authors give the only comment that the value of phase shift from low to high fields which is less than 180 cannot be explained just by a constant shift of the calibration. The comparison of the given very interesting result with the results described in [65, 66] leads to the conclusion that the nature of the appearance of the angle between the maximum of the signal registered and reference signal can be entirely the same. In other words, the level of stationary signals in Bi2212 single crystal seems to be governed by the relaxation time, connected with transfer of its electronic system into excited state, that is, with finite time of the photons' absorption. To confirm the given interpretation the study of the signal dependence on the microwave power level is necessary (the given dependence was not represented in the work cited). However, the fact itself of the observation of the phase angle is the strong indication, that the microwave field quantisation takes place, that is, the most correct description of the results obtained can be achieved within the QED theory use.

It is clear that the dynamics of spectroscopic transitions cannot be described in the systems above described by known Bloch equations or Torrey equations both in classical and semiclassical forms even qualitatively, since the process of the photon absorption (or emission) is suggested in Bloch equations or Torrey equations in implicit form being to be instantaneous. It raises the concernment of the works [39, 73], where the equations for the dynamics of spectroscopic transitions are represented, which are appropriate for the case of the processes of the photon absorption (or emission) with any characteristic times.

The equations in the the works [39, 73] are the system of difference-differential equations, they can describe the dynamics of spectroscopic transitions for both radio and optical spectroscopy for the model, representing itself the 1D-chain of N two-level equivalent elements coupled by exchange interaction (or its optical analogue for the optical transitions) between themselves and interacting with quantized EM-field and quantized phonon field. Naturally the equations are true for any 3D system of paramagnetic centers or optical centers by the absence of exchange interaction. In comparison with semiclassical description, where the description of dynamics of spectroscopic transitions is exhausted by one vector equation (Landau-Lifshitz equation or Landau-Lifshitz based equation), by quantum electrodynamic consideration the Landau-Lifshitz type equation describes the only one subsystem of three-part system - photon field-electronic subsystem of the matter-phonon field. The complete system of difference-differential equations include the matrix equations for the photon field and for the phonon field. By the way, let us remark, that it has been shown in [39], that Landau-Lifshitz equation is fundamental physical equation underlying along with the dynamics of magnetic moment motion, the dynamics of spectroscopic transitions and transitional phenomena, however, let us accentuate once again, its use is sufficient the only by classical or semiclassical description of the interaction of EM-field with matter.

We wish to concern the comparison of the photon scalar field function with the electron scalar field function. The description of an electron has to take into account that the electron has the rest mass with the essential value. There is the discussion in the modern literature on the origin of the electron mass, and some other mechanisms, being to be different from the Higgs mechanism are proposed, however it is not the subject for the given review. It is undestandable, that the view of the scalar field function of an electron seems to be dependent on the way of the mass obtaining by given particles, which is under discussion at present. We, however, wish to remark that there is the progress in understanding of the structure of the electron. The electron was earlier considered to be the pointlike object, the size of which does not exceed the value 10^{-16} cm [74]. Let us remark, that it has quite recently appeared a new viewpoint on degree of electron localization [75]. "The observable gravitational and electromagnetic parameters of an electron: mass m, spin $J = \hbar/2$, charge e and magnetic moment $ea = e\hbar/2m$ indicate that the consistent with Einstein-Maxwell gravity electron should lead to a Kerr-Newman background geometry. Contrary to the widespread opinion that gravity plays essential role only on the Planck scales, the Kerr-Newman gravity displays a new dimensional parameter $a = \hbar/2m$, which, for parameters of an electron, corresponds to its Compton wavelength and is very far from the Planck scale." It is further argued in [75] "that, although gravitational field of an electron is extremely weak, extremely large spin of the electron produces the Kerr geometry, which has very essential topological changes at the Compton distance. The Kerr geometry is formed by a congruence of twistor null lines, which are focused on the Kerr singular ring, forming a branch line of Kerr background on two sheets. The gravitational and electromagnetic fields are also focused on the Kerr ring, forming a sort of a closed string, structure of which is close to described by Sen field model of a heterotic string. The stringlike Kerr-Newman electron contradicts to the claims on a structureless electron, but it confirms peculiar role of the Compton area of a "dressed" electron in QED and matches with the known limit of localization of the Dirac electron."

Therefore, the detailed comparison of the photon scalar field function with the electron scalar field function seems to be the subject of the subsequent studies.

5 Conclusions

a The status of the photon in the modern physics was analysed both within the frames of the Standard Model of the physics of elementary particles and within the frames of the quantum electrodynamics. Within the frames of the Standard Model of the physics of elementary particles the photon is considered to be the genuine elementary particle.

b The development of the viewpoint of the experts in the quantum electodynamics theory (in particular, in quantum optics) is also analysed. It was shown its change from the opinion, that the description of the photon to be the particle is impossible and that the photon scalar field function does not exists to the viewpoint on the photon coinciding with its representation in the Standard Model of the physics of elementary particles.

c The quantized Maxwellian EM-field represents itself, according to the new conceptual model reviewed, the sets of 1D rays, the own structure of each ray is discrete - 1D-lattice of spin-1 bosons. The structure of EM-field in boson model resembles the matter structure of the carbon frame of organic polymers like to *trans*-polyacetylene. Photons in the given concept are the corpuscles, propagating along EM-field boson-"atomic" chains, which in fact represent themselves the medium for the photons' propagation. In the structural aspect photons in usual conditions are chargeless spin 1/2 topological relativistic solitons of Su-Schrieffer-Heeger family. Spinless charged solitons of the same family can also be formed in so-called "doped" EM-field structure. From the given model follows the conclusion, that photons, being to be fermions [but not spin-1 gauge bosons] cannot be usual messengers of electromagnetic interaction. It distinguishes strongly the electromagnetic interaction from the weak force interaction, the messengers of which are W and Z bosons.

d The origin of waves in the EM-field boson-"atomic" structure is determined by the mechanism, being to be quite analogous to the formation of Bloch waves in the solid state of condensed matter, in particular, in the carbon frame of organic polymers. The expression for the corresponding wave function $\psi(\vec{r}, t)$ representing itself the set of Bloch-like waves is given. It is the following

$$\psi(x, y, z, t) \equiv \psi(\vec{r}, t) = \sum_{i=1}^{Q} \{u_{\vec{k}_j}(\vec{r}) \exp \vec{k}_j \vec{r} \sin[-2\pi\nu_j t + \frac{S_j(\vec{r})}{K_j}]\}, \tag{5.1}$$

where K_j is given by the value $h/2\pi$, which is independent on j, and $\nu_j = \frac{E_j}{h}$, the functions $u_{\vec{k}_j}(\vec{r}), j = \overline{1, Q}$, have the period of the sublattice j. Just, the given functions allows to describe correctly the wave properties of the light, including the interference. Corpuscular properties of EM-field including those ones by its interaction with matter are described by independent scalar field function $\Psi(\vec{r}, t)$, obtained from the solution of Schrödinger equation [nonstationary in general case] and usually called wave function. The term "wave" seems to be incorrect in application to the function $\Psi(\vec{r}, t)$ and has to be corrected in all literature on quantum theory, including textbooks.

e The full variant of Schrödinger's theory, taking into consideration two scalar functions seems to be necessary to use to describe correctly the quantised EM-field properties including corpuscular-wave dualism [which is explained then in a natural way] and to describe the interaction of quantised EM-field with matter.

f The physics of the quantum absorption process is analysed. It is argued in accordance with Dirac guess, that the photon revival takes place by its absorption. Being to be a relativistic topological soliton, it seems to be keeping safe after the energy and impulse transfer to absorbing system in a pinned state, possessing the only by spin.

g The experimental results are analysed, which prove, that the time of the transfer of absorbing systems into an excited state is finite and moreover, that it can govern the stationary signal registered. The given result seems to be significant for all the stationary spectroscopy, in which at present the transfer of absorbing systems in an excited state is considered to be instantaneous. The value of the time of transfer into excited state in the samples studied in [65, 66] was evaluated to be equal $\tau_g = 5.8 \times 10^{-7}s$. It is accentuated, that it is the direct indication that in the samples studied in [65, 66] the longlived coherent states are realized, which in its turn indicates on the practical significance of the given systems for the modern technology.

Competing Interests

The authors declare that no competing interests exist.

References

[1] Planck M. Über das Gesetz der Energieverteilung im Normalspektrum [On the Law of the Energy Distribution in the Normal Spectrum], Ann.d.Phys. 1901;4:553-563. Verhandlungen der Deutsch.Physikal.Gesellsch. 1900;2:202-237.

[2] Einstein A. Collected Scientific Works, M. 1966;3:92,128.

[3] Einstein A. Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt [Concerning an Heuristic Point of View toward the Emission and Transformation of Light], Ann. d. Phys. 1905;17:132-148.

[4] Lewis GN. The Conservation of Photons, Nature. 1926;118:874-875.

[5] Born M, Jordan P. Zur Quantenmechanik, Zeitschrift für Physik. 1925;34:858-888.

[6] Born M, Heisenberg W, Jordan P. Zur Quantenmechanik II, Zeitschrift für Physik. 1926;35:557-615.

[7] Dirac PAM. The Quantum Theory of Emission and Absorption of Radiation, Proc. Roy. Soc. A. 1927;114:243-265.

[8] Dirac PAM. The Physical Interpretation of the Quantum Dynamics, Proc. Roy. Soc. A. 1927;113:621-641.

[9] Nöther E, Nachrichten von der Gesellschaft der Wissenschaften zu Gottingen, Mathphys. Klasse. 1918;235-257.

[10] Compton AH. The Spectrum of Scattered X-Rays, Phys. Rev. 1923;22:409.

[11] Compton AH. A Quantum Theory of the Scattering of X-Rays by Light Elements, Phys.Rev. 1923;21:483.

[12] Lebedev PN. Journal of Russian Physico-Chemical Society. 1901;33:53.

[13] Dempster AJ, Batho HF. Light Quanta and Interference, Phys. Rev. 1927;30:644-648.

[14] Braginsky VB, Khalili FYa. Quantum Measurements, Cambridge University Press, Cambridge, GB. 1992;193.

[15] Dmitri Yerchuck, Alla Dovlatova, Andrey Alexandrov. Boson Model of Quantized EM-Field and Nature of Photons, 2nd International Conference on Mathematical Modeling in Physical Sciences; 2013. Journal of Physics: Conference Series. 2014;490:012102-8. DOI:10.1088/1742-6596/490/1/012102

[16] Scully MO, Zubairy MS. Quantum Optics, Cambridge University Press, 1997, 650 pp

[17] Wolfgang Schleich. Quantum Optics in Phase Space, WILEY-VCH Verlag, Berlin, Weinheim, New York, Chichester, Brisbane, Singapore, Toronto. 2001;695.

[18] Dovlatova A, Yearchuck D. QED Model of Resonance Phenomena in Quasionedimensional Multichain Qubit Systems, Chem. Phys. Lett. 2011;511:151-155.

[19] Slepyan GYa, Yerchak YD, Hoffmann A, Bass FG. Strong Electron-Photon Coupling in a One-Dimensional Quantum Dot Chain: Rabi Waves and Rabi Wave Packets, Phys. Rev. B. 2010;81:085115.

[20] Yerchuck D, Dovlatova A. Quantum Optics Effects in Quasi-One-Dimensional and Two-Dimensional Carbon Materials, J.Phys.Chem.,C, DOI: 10.1021/jp205549b. 2012;116:63-80.

[21] Takaomi Shigehara, Hiroshi Mizoguchi, Taketoshi Mishima, Taksu Cheon. Chaos Induced by Quantisation, Phys. Rev. E. 1998;1-7.

[22] Dirac PAM. The Quantum Theory of Dispersion, Proc. Roy. Soc.A. 1927;(114):710.

[23] Alla Dovlatova and Dmitri Yerchuck. Concept of Fully Dually Symmetric Electrodynamics, Journal of Physics: Conference Series. 2012;343:012133. DOI:10.1088/1742-6596/343/1/012133

[24] Schrodinger E. Die gegenwärtige Situation in der Quantenmechanik, Die Naturwissenschaften. 1935;50:844-849.

[25] Schrodinger E. Berl. Ber., I6; April 1931.

[26] Schrodinger E. Annales de l'Institut H. Poincare, 269. Paris; 1931.

[27] Schrodinger E. Cursos de la universidad internacional de verano en Santander, I. Madrid, Signo. 1935;60.

[28] Pauli W. Handbuch der Physik (ed.H.Geiger and K.Scheel), 1st edn, Springer. 1926;23:1-278.

[29] Galapon E, The VIIth Int.Conf. Quantum Theory and Symmetries, Abstracts, Prague. 2011;51.

[30] Galapon E, Time Operator Canonically Conjugate to a Hamiltonian with Non-empty Point Spectrum, Proc. Roy. Soc. Lond. A. 2002;458:451-472.

[31] Schrödinger E. Quantisierung als Eigenwertproblem (Erste Mitteilung), Annalen der Physik (Fierte Folge). 1926;79:361.

[32] Schrödinger E, Quantisierung als Eigenwertproblem (Zweite Mitteilung), Annalen der Physik (Fierte Folge). 1926;79:489.

[33] Schrödinger E. Quantisierung als Eigenwertproblem (Dritte Mitteilung), Annalen der Physik (Fierte Folge). 1926;80:437-490.

[34] Schrödinger E. Quantisierung als Eigenwertproblem (Vierte Mitteilung), Annalen der Physik (Fierte Folge). 1926;81:109-139.

[35] Dmitri Yerchuck, Alla Dovlatova, Felix Borovik, Yauhen Yerchak, Vyacheslav Stelmakh, To Principles of Quantum Mechanics Development, International Journal of Physics. 2014;2(5):129-145. DOI: 10.12691/ijp-2-5-2

[36] Schrödinger E, An Undulatory Theory of the Mechanics of Atoms and Molecules, Phys.Rev. 1926;28(6):1049-1070.

[37] Yearchuck D, Alexandrov A and Dovlatova A, To Nature of Electromagnetic Field, Appl. Math. Comput. Sci. 2011;3(2):169-200.

[38] Dovlatova A, Yerchuck D. Concept of Fully Dually Symmetric Electrodynamics, 7th International Conference on Quantum Theory and Symmetries (QTS7), J. Physics: Conference Series. 2012;343:(012133):23. DOI:10.1088/1742-6596/343/1/012133

[39] Yearchuck D, Yerchak Y, Dovlatova A. Quantum Mechanical and Quantum Electrodynamic Equations for Spectroscopic Transitions, Optics Communications. 2010;283:3448-3458.

[40] Born M, Z. f. Phys. 1926;38:803-827; Born M, Das Adiabatenprinzip in der Quantenmechanik. 1926;40:167; Born M, Experiment and Theory in Physics, Cambridge University Press. 1943;23.

[41] Landau LD, Lifshitz EM. Quantum Mechanics, Moscow, Nauka. 1989;768.

[42] Abdelhak Djouadi, The Higgs Mechanism and the Origin of Mass, The 8-th Int.Conf. on Progress in Theor.Phys., AIP Conf. Proc. 2012;1444:45-57. DOI: 10.1063/1.4715399

[43] Kalanand Mishra, The Frontier of High Energy Physics and the Large Hadron Collider, Padjadjaran Int.Phys.Symp.2013, AIP Conf. Proc. 2013;1554:9-11. DOI: 10.1063/1.4820273

[44] Ding-Yu Chung, Ray Hefferlin. The Higgs Boson in the Periodic System of Elementary Particles, Journal of Modern Physics. 2013;4:21-26. DOI:10.4236/jmp.2013.44A004

[45] Edgar E Escultura. The Logic and Fundamental Concepts of the Grand Unified Theory, Journal of Modern Physics. 2013;4:213-222. Available: http://dx.doi.org/10.4236/jmp.2013.48A021

[46] Garisto R, Agarwal A. Scientific American. 2012;307(3).

[47] Power EA. Introductory Quantum Electrodynamics, Longman, London; 1964.

[48] Kramers HA. Quantum Mechanics, North-Holland, Amsterdam; 1958.

[49] Bohm A. Quantum Mechanics: Foundations and Applications, Springer-Verlag, N.-Y.,Berlin, Heidelberg, Tokyo, 1986, M., Mir. 1990;720.

[50] Alla Dovlatova, Dmitri Yerchuck, Felix Borovik, arXiv:1112.3339 [cond-mat.str-el]; 2013.

[51] Alla Dovlatova, Dmitri Yerchuck, Felix Borovik, Concept of Quantum Fermi Liquid and Spin-Charge Separation Effect in 1D Systems, Progress in Nanotechnology and Nanomaterials. 2014;3(3):37-56.

[52] Emery VJ, Luther A. Backward scattering in the one-dimensional electron gas, Phys. Rev. Lett. 1974;33:589-592.

[53] Jackiw R, Rebbi C. Solitons with fermion number $\frac{1}{2}$, Phys. Rev. D. 1976;13:3398-3409.

[54] Anderson PW. The resonating valence bond state in La_2CuO_4 and superconductivity, Science. 1987;1196-1198.

[55] Debye P. Der Warscheinlickeitsbegriff in der Theorie der Strahlung, Ann.d.Phys. 1910;33(4):1427-1434

[56] Wolfke M. Zur Quantentheorie, Verh. DPG. 1913;15:1123-1129. Wolfke M, Phys.Zs. 1914;15:308-311; Wolfke M, Einsteinsche Lichtquanten und Raumliche Struktur der Strahlung, Phys. Zs. 1921;22:375-379.

[57] Boya Luis J, Duck Ian M, Sudarshan ECG. Deduction of Planck's Formula from Multiphoton States, arXiv:quant-ph/0010010v1 2 Oct 2000.

[58] Berestecky VB, Lifshitz EM, Pitaevsky LP. Quantum Electrodynamics, M., Nauka. 1989;728.

[59] Fedoruk GG, Rutkovskii IZ, Yerchak DP, Stelmakh VF, Zhurnal Experimentalnoi i Teoreticheskoi Fiziki. 1981;80(5):2004-2009. Fedoruk GG, Rutkovskii IZ, Erchak DP, Stel'makh VF, Applicability of Bloch Model for Describing the Dynamics of Magnetic-Resonance Signals, Sov. J. Exp.Theor. Physics, USA. 1981;53(5):1042-1044.

[60] Yerchak DP, Rutkovskii IZ, Stelmakh VF, Fedoruk GG. Nonsteady State Radiation Defects' EPR in Silicon, In: "Questions of Atomic Science and Technique. Radiation Damage Physics and Radiation Materialkeeping", Kharkov. 1982;2(21):79-80.

[61] Su WP, Schrieffer JR, Heeger AJ. Soliton Excitations in Polyacetylene, Phys. Rev. B. 1980;22:2099-2111.

[62] Escultura E E, Quantum Gravity, In: E. E. Escultura, Ed., Scientific Natural Philosophy, Bentham Ebooks. 2011;61-80. Available: http://www.benthamscience.com/eBooks

[63] Escultura EE, The Mathematics of the Grand Unified Theory, Journal of Nonlinear Analysis, A-Series: Theory: Method and Applications. 2009;71:420-431.

[64] Ryvkin SM. Photoelectric Phenomena in Semiconductors, M., Fizmatgiz. 1963;496.

[65] Ertchak DP, Efimov VG, Stelmakh VF. EPR Spectroscopy of Low-Dimension Structures Produced in Natural Diamonds and Synthetic Diamond Films by Ion Implantation (Review), J. Appl. Spectroscopy. 1997;64:(4):433-460.

[66] Ertchak DP, Efimov VG, Stelmakh VF, Martinovich VA, Alexandrov AF, Guseva MB, Penina NM, Karpovich IA, Varichenko VS, Zaitsev AM, Fahrner WR, Fink D, The Origin of Dominating ESR Absorption in Ion Implanted Diamond, Phys. Stat. Sol. b. 1997;203:529-547.

[67] Erchak DP, Efimov VG, Zaitsev AM, Stelmakh VF,Penina NM, Varichenko VS, Tolstykh VP. Peculiarities of Damage in Diamond Irradiated by High Energy Ions, Nucl.Instr.Meth in Phys. Res. B. 1992;69:443-451.

[68] Jaynes ET, Cummings FW. Comparison of Quantum and Semiclassical Radiation Theories with Application to the Beam Maser, Proc. IEEE. 1963;51(1):89-109.

[69] Cummings FW, Phys. Rev.1965;140:A1051.

[70] Eberly JH, Narozhny NB, Sanchez-Mondragon JJ, Periodic Spontaneous Collapse and Revival in a Simple Quantum Model, Phys. Rev. Lett. 1980;44(20):1323-1326.

[71] Weger M, Passage Effects in Paramagnetic Resonance Experiments, The Bell System Technical Journal. 1960;39(4):1013-1112.

[72] Shaltiel D, Krug von Nidda HA, Shapiro B Ya, Loidl A, Tamegai T, Kurz T, Bogoslavsky B, Rosenstein B, Shapiro I, Investigating Superconductivity with Electron Paramagnetic Resonance (EPR) Spectrometer, In: Superconductors - Properties, Technology, and Applications, Dr.Yury Grigorashvili (Ed.), InTech. 2012;436:63-82.

[73] Alla Dovlatova and Dmitri Yerchuck, Quantum Field Theory of Dynamics of Spectroscopic Transitions by Strong Dipole-Photon and Dipole-Phonon Coupling, ISRN Optics. Article ID 390749. 2012;10. DOI:10.5402/2012/390749

[74] Physical Encyclopedia. (Ed.in-Chief Prokhorov A.M) v.5, pp M. 1998;688:540-545.

[75] Burinskii A. The VIIth International Conference Quantum Theory and Symmetries. Prague, Abstracts, August 7-13. 2011;24.

Peer-review history:
The peer review history for this paper can be accessed here (Please copy paste the total link in your browser address bar)
www.sciencedomain.org/review-history.php?iid=768&id=5&aid=7529