ON THE QUANTUM ELECTRODYNAMICS OF NANOSYSTEMS

Gritsunov A. V., Bondarenko I. N., Galat A. B., Glukhov O. V., Pashchenko A. G.
Kharkiv National University of Radio Electronics
61166, Kharkiv, Nauky ave., 14, dep. Microelectronics, electronic devices and appliances
Tel. +380 57 7021362
E-mail: gritsunov@gmail.com

Problems of quantum dynamics of nanoobjects essential for development of new nanoelectronic systems are discussed. According to the theory of natural oscillatory systems (NOSs), "interaction" between the objects is interpreted as a quantum-dynamic phenomenon meaning a stable trend arising from the quantum chaos. As an opposite, "interchange" is denominated as the permanent stochastic exchange with action quanta between different NOSs in 4D spacetime, being the physical base of the quantum chaos. The Tetrode-Wheeler-Feynman's concept of "direct interparticle action" is reconciled with both the quantum radiation-absorption and the Coulomb interaction. A conservation law for the action is supposed as a necessary condition for the momentum-energy conservation. The "classic" conservation law for the momentum-energy is considered as derivative, being valid for the momentum as well as some physical value that is an integral over 3D space from a linear combination of stress-energy tensor principal diagonal terms. Such redefinition enables the unconditional quantization of the energy unlike "orthodox" quantum theory.

Introduction

The contemporary advance of electronic and robotic technologies to the nanoworld reanimates old fundamental problems of the quantum mechanics (QM) and the quantum electrodynamics (QED). Despite striking achievements in the engineering applications of these disciplines, there is no clear theoretical understanding the quantum world behavior yet. Such opinion is confirmed, e.g., by the recent discovery of abnormally high radiation-absorption factor for nanoscale emitting systems as well as other surprising quantum effects [1, 2]. It is obviously that new, more consistent, theory of QED phenomena is wanted.

Concepts of natural electromagnetic (EM) and electron-positron (EP) distributed oscillatory systems (NEMOS, NEPOS respectively), as real physical bases for the de Broglie matter waves and as alternatives to the "physical vacuum" of QED, were proposed by one of us [3]. A discipline named as "Theory of natural oscillatory systems" (TNOS) is developing in ResearchGate project of the same name [4]. Some fundamental problems of QED, in their specific interpretation, are considered in this paper.

Preliminary Physical Issues

The 4D pseudo Euclidean formalism with imaginary time ("1, 1, 1, *i*") is assumed. The Cartesian coordinate system is used; x, y, and z are the real spatial coordinates; t is a temporal coordinate with dimension of imaginary length. Four-vectors in the Minkowski spacetime are mixed-valued with real spatial components and imaginary temporal one.

Instead of the EM potential four-vector and de Broglie EP wavefunction, complex-valued four-vector aleph-functions $\vec{\aleph}^{\gamma}(x,y,z,t)$ and $\vec{\aleph}^{e}(x,y,z,t)$ respectively, each having real spatial components and imaginary temporal, are introduced for natural oscillatory systems (NOSs). EM aleph-function $\vec{\aleph}^{\gamma}$ is restricted with the Lorenz gauge $\vec{\nabla}\cdot\vec{\aleph}^{\gamma}\equiv 0$. EP aleph-function $\vec{\aleph}^{e}$ is restricted with both the Lorenz gauge $\vec{\nabla}\cdot\vec{\aleph}^{e}\equiv 0$ and a spatial flat rotation ("media 2D twisting") condition, namely, $\aleph^{e}_{\xi}\equiv 0$ in some "privileged" rest frame system, where ξ is only

one of the spatial coordinates (arbitrary). In contrast to $\vec{\aleph}^{\gamma}$, $\vec{\aleph}^{e}$ has no "potential" eigenfunctions (with spin of zero) in one's Fourier expansion, therefore, according to the angular momentum quantization rules, spins of NEPOS eigenmodes are of $\pm 1/2$, not of $-1,0,+1$, as for NEMOS.

The physical senses of $\vec{\aleph}^{\gamma}$ and $\vec{\aleph}^{e}$ are local deviations of NEMOS and NEPOS respectively from their "undisturbed" states along the respective axes. According to such interpretation, both $\vec{\aleph}^{\gamma}$ and $\vec{\aleph}^{e}$ must be gauge-dependent (i.e., to tend to zero far off from a matter), but this is insignificantly in the quantum theory, because any invariable in the spacetime addition to $\vec{\aleph}^{\gamma}$ or $\vec{\aleph}^{e}$ has no action quantum, so, cannot be involved in the interaction.

So-called four-number $\vec{m} = \{m_x, m_y, m_z, im_t\}$, where $m_\tau = 0, \pm 1, \pm 2, \ldots$; τ means one of spatio-temporal coordinates, is introduced to "elegant" enumeration of NEMOS and NEPOS eigenfunctions.

The Coulomb Interaction

The longstanding Wheeler-Feynman's (and, earlier, Hugo Tetrode's) idea of "advanced" EM interactions along with "retarded" ones [5] was recently reanimated by Y. Aharonov, "patriarch" of contemporary quantum theory. Such notion completely adjusts with the basic concepts of TNOS: "almost free" (i.e., "non-virtual") photons contain too small action to store, e.g., total action of annihilating EP pair. Only "direct" collective transfer with multiple harmonic components of a NEMOS wave packet is possible.

The Coulomb interaction between fermions is a specific case of the radiation-absorption when photons are essentially "forced," i.e., having relatively large actions. The "interaction" is interpreted as a stable trend in variation of the momenta or the momenta-energies of NEPOS wave packets arising from the quantum chaos. The latter is a result of random mutual conversion with action quanta ("interchange") between NEPOS and NEMOS in 4D spacetime. If two or more immovable "electrons" are placed in their "common" EM potential, NEMOS performs a stochastic mutual exchange with momentum between ones (i.e., the Coulomb repulsion) in addition to the "localizing" effect for each wave packet taken separately [3]. For moving "electrons," this exchange includes also energy.

The magnetic moment of "electron" is a result of the "uncertainty" in its own angular momentum. Stochastic changes of direction of an "electron rotation axis" are compensated by "mirror" variations in angular momentum of NEMOS, so, total angular momentum of the insulated system "electron in its own EM potential" remains objectively unchanged.

The Radiation-Absorption

The similar interaction process between atoms in the time domain transfers both momentum and energy and is known as "radiation-absorption." Mechanism of the quantum EM interaction is supposed to be the same for both time-dependent (e.g., radiating-absorbing atoms) and static (e.g., mutually repulsive "electrons") systems. We must put into our hypothesis the Tetrode-Wheeler-Feynman's concept of "advanced" EM interactions along with "retarded" ones [5] to explain the temporal localization of EM wave packets, which transfer the energy.

E.g., if an excited atom #1 has transferred a quantum of its extra momentum-energy (and, respectively, negative and positive quanta of the action) to an atom #2 via a "photon," this act may be still "rolled back" by an "antiphoton" ("the Schr dinger's cat can be revivified"). Only

if atom #2 has retransmitted the obtained quantum to an atom #3, this quantum no longer can be returned to atom #1 ("a measurement has been made, the cat is dead, sorry…").

Why atom #3 cannot return the obtained quantum to atom #2, so, one will return it to atom #1 (remember, these processes cannot be described as "flowing in time," so, "will" term is not quite suitable here)? Such situation is theoretically possible; however, the probability of the "rolling back" all chain of the events decreases dramatically as the number of possible variants of the events enlarges. Atom #3 can transfer the obtained quantum to an atom #4, or atom #5, *etc*, not necessarily return it to the atom #2. Figuratively, the unhappy cat is a victim of the second law of thermodynamics.

Quantum oscillating systems having two and more stable or quasi-stable states (e.g., atoms) are, formally, the same "observers" as people with their "classic" apparatus. Just they seal the fate of the Schr din ger's cat long before the box is opened. A "macroscopic observer" can be sure what has happened in the quantum system only when the above process has gone enough far to make a "rollback" practically impossible. Until then, the observer's knowledge can be only probabilistic.

If a single excited atom is placed in the Universe, it would never radiate, because "almost free" photon cannot accumulate by oneself the difference between the actions of excited and unexcited atoms (neither positive nor negative parts of their total actions). Further, if only two atoms existed in the world, some is excited while other is unexcited at some instant, they would "beat" like two weakly coupled harmonic oscillators. The mutual coupling factor is defined by the fine-structure constant α as well as spatial characteristics of the atoms. Three and more mixed excited and unexcited atoms in the Universe, evidently, must oscillate like a network of harmonic oscillators weakly coupled each with another.

The Momentum-Energy Relations

According to TNOS [3, 4], the momentum-energy is a dynamic value arising from the "movement" of 3D world over 4D spacetime in the temporal direction. Excited NOS eigenmodes "vibrate" like animated cartoon from the point of view of a 3D observer. The frequency of this vibration describes the eigenmode's energy, while the quickness and the direction of spatial displacement of the oscillation's phase define its momentum. In other words, momentum-energy is defined as flow of the action through 3D world.

It is easy to see that the "orthodoxal" formula of QED for quantization of the total momentum-energy four-vector of a NOS $\vec{m}$-th eigenmode $\vec{W}_{\vec{m}} = \eta K_{\vec{m}} \vec{k}_{\vec{m}}$, where η is the Planck constant; $\vec{k}_{\vec{m}}$ is the wave four-vector of $\vec{m}$-th eigenmode; $K_{\vec{m}}$ is the mode occupation factor [4], is not so universal. First, this is valid only for "free" or matter-like eigenmodes, i.e., having $k_{\vec{m}}^2 \le 0$. Second, this not considers the existence of both positive and negative action quanta as well as the same sign of energy for "particles" (with $k_{\vec{m}t} > 0$) and "antiparticles" (with $k_{\vec{m}t} < 0$). Real 3D observer cannot determine actual sign of $k_{\vec{m}t}$ component in direct way. Only hypothetic "4D observer" can distinguish "positive" and "negative" directions of the wave vector for fermions. E.g., energies of "particle" and "antiparticle" have the same sign. The sign of $\vec{m}$-th eigenmode momentum depends on the relative orientation of $k_{\vec{m}\xi}$ and $k_{\vec{m}t}$ components.

Therefore, it would be reasonably to evaluate the total momentum-energy of individual eigenmodes and of a while NOS by means of integrating the respective components of the four-tensor of stress-energy density over all 3D volume of Universe. There are two form of this

tensor: "classic" $[w](x,y,z,t)$ and "quantum" $[p](x,y,z,t)$ ones. They differ only in the expressions for the principal diagonal terms.

The "classic" form is evaluated from the hypothesis of spacetime uniformity according to the Noether's theorem. This results in conservative but not always quantized energy definition

$$w_{\tau\tau'} = \sum_{\tau''} \frac{\partial \aleph_{\tau''}}{\partial \tau} \left| \frac{\partial h}{\partial(\partial \aleph_{\tau''} / \partial \tau')} \right| - I_{\tau\tau'} h, \tag{1}$$

where $h(x,y,z,t)$ is the action four-density [1] for non-interacting NOS:

$$h = \frac{i}{2}\left[(\vec{\nabla}\aleph_x)^2 + (\vec{\nabla}\aleph_y)^2 + (\vec{\nabla}\aleph_z)^2 + (\vec{\nabla}\aleph_t)^2 + k_*^2 (\vec{\aleph})^2 \right]; \tag{2}$$

k_* is a NEPOS cutoff wavenumber (a TNOS equivalent for "particle rest mass" m_*); $[I]$ is the unit four-tensor.

Substituting (2) to (1), one can see that the components of tensor $[w]$ are written as

$$w_{\tau\tau'} = 2i \frac{\partial \vec{\aleph}}{\partial \tau} \cdot \frac{\partial \vec{\aleph}}{\partial \tau'} - I_{\tau\tau'} h. \tag{3}$$

Evidently, "classically" defined stress-energy density (3) always ensures the total momentum-energy conservation in 3D Universe. Unfortunately, it can hardly be said that this agrees with the quantization basic principles. If energy is correlated with the temporal variation of a certain wave process, some forms of "classic" energy embodiment cannot be quantized (e.g., "energy" of EM potential of "rest electron"). The violation of the quantization rules at least for one of kinds of energy existence breaks down fundamentals of the quantum theory, because mutual transformation of "quantized" and "non-quantized" forms of energy cannot occur by discrete portions.

Unlike the classic EM theory, all components of the four-tensor of "quantum" stress-energy density $[p]$ of a NOS (including diagonal ones) are not based on the spacetime uniformity hypothesis and are defined in TNOS in simple and uniform manner

$$p_{\tau\tau'} = 2i \frac{\partial \vec{\aleph}}{\partial \tau} \cdot \frac{\partial \vec{\aleph}}{\partial \tau'} \tag{4}$$

differing from (3) in the principal diagonal terms. "Quantum" stress-energy density (4) is always quantized. E.g., a "quantum" energy always assumes some non-stationary (time-dependent) process existence, so, EM potential of the "rest electron" cannot possess any energy. However, the "quantum" energy, as a dynamic entity, is, generally, non-conservative value for 3D Universe (the momentum is conservative as usual). Conservation rules, following from the Noether's theorem applied to the spatio-temporal coordinates, are fit now to other values, namely, linear combinations of the principal diagonal terms. E.g., for a hypersurface of $t = \text{const}$ (our 3D world), the value keeps:

$$w_{tt} = p_{tt} - h = -p_{xx} - p_{yy} - p_{zz} + p_{tt} - k_*^2(\vec{\aleph})^2 \qquad (5)$$

(actually, this is arithmetical sum of all components; the differing sign for p_{tt} is compensated by imaginary value of t). During an interaction between two and more "particles," the "quantum" energy p_{tt} transfers to the "quantum" stress $p_{xx} + p_{yy} + p_{zz}$ and vice versa. This is an equivalent of mutual conversation of "kinetic" and "potential" classic energies.

Conclusion

Despite striking achievements in the engineering applications of QM and QED, there is no consensus in understanding the theoretical bases of quantum world behavior yet. Because characteristic sizes of nanorobot components are almost of the same order as typical de Broglie wavelengths for their parts, the design of those must be certainly performed according to the quantum laws, not classical. However, some fundamental bugs of "Copenhagen interpretation" make the outlook of further progress not quite definite.

TNOS considers spatially or spatio-temporally localized wave packets of NOSs as full-value equivalents of "elementary particles." The proposed concept consistently describes behavior of de Broglie waves in conductors, semiconductors, and superconductors. The described results may be useful for the development of new nanoelectronic components and quantum computers.

References

Wuttke, C. and A. Rauschenbeutel, "Thermalization via Heat Radiation of an Individual Object Thinner than the Thermal Wavelength," arXiv: 1209.0536v3 [quant-ph] 18 Jul 2013.

Slepyan, G., A. Boag, V. Mordachev *et al.*, "Anomalous Electromagnetic Coupling via Entanglement at the Nanoscale," New J. Phys., vol. 19, 023014, 2017.

Gritsunov, A., I. Bondarenko, A. Pashchenko, and O. Babychenko, "Theory of Natural Oscillatory Systems and Advance in Nanoelectronics," 14th Int. Conf. on Advanced Trends in Radioelectronics, Telecomm. and Computer Eng. (TCSET), Lviv-Slavske, Ukraine, p.p. 92-97, 2018.

Gritsunov, A. V., "Theory of natural oscillatory systems," ResearchGate project [Online]. Available: https://researchgate.net/project/Theory-of-Natural-Oscillatory-Systems

Wheeler, J. A. and R. P. Feynman, "Classical Electrodynamics in Terms of Direct Interparticle Action," Rev. Modern Phys., vol. 21, no. 3, 1949.