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Localized States for the Photon

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An approach to mechanics based solely on the very fact of the top-speed signal existence, rather than of its value constancy, lends itself to a plausible concept of the photon's localization

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In its conventional form, relativistic quantum mechanics cannot provide the massless photon with a spatial wave function, the absolute square of which could form the probability density of photon locations (see, e.g., Ref.1). Actually, the deep cause of this drawback lies in the basic concepts of Newtonian mechanics, in which no top velocity is there, that is, for any motion however fast, a faster one exists. This is easily seen already in the 'zero-mass puzzle': A massless body could still be accelerated. Since any force, however small, might cause this acceleration, the whole universe must be involved in this problem, so making it useless.

Formalism of Top-Speed Signals (TSS) oscillations counting makes it possible to dispense with metrical concepts and to formulate experiments solely in terms of the numbers of such oscillations and ratios of these numbers ([2],[3]). In particular, slit experiments can be explained directly by means of probabilities rather than by introducing first a wave function and only then defining probability localization as its absolute square.

Aiming at the prediction of final contacts, a relevant procedure to design trajectories by means of TSS oscillations counting had been developed ([3]). In the conventional approach, contacts of the body that is in question in the problem are registered with special detectors: "material points" plus attached clocks plus rulers plus reference frames. At any moment one of such detectors must signal collision, otherwise it is decided that there is no body at all. Once applied to microscopic particles, the macroscopic detector scatters them (elastically, i.e., preserving absolute values of their momenta), and this scattering becomes important, if acting force is sufficiently small. Quantum mechanics describes such a situation probabilistically, still keeping the same variables as in macroscopic applications.

In order to present physics in terms of TSS oscillations counting, the system of parallel trajectories ([3]) allows for replacing "material points" with an alternative detector –*order*. A short description of this method in the Ref.3 will be presented below in more details and in the form relevant for application to the photon. In so doing we confine ourselves to non-relativistic cases, in which only one non-annihilating particle is in question. The centers of *orders* move like test or probe bodies ([3]).

In a completely uniform *order*-detector moving in z-direction (Fig.1), top-speed signal (TSS) oscillations are equal in numbers and reciprocally synchronized over all columns and lines. If this *order* detects its contact with a particle then this particle is positioned somewhere inside, but neither its position there, nor the velocity is being so determined. It could be added however that also the number of these contacts is being determined; then the detection of only one contact would specify the smallest velocity with respect to the *order*, while the position of the particle inside the *order* remains uncertain. Yet, this *order* cannot define the value of this lowest velocity solely in terms of the top-speed signal oscillations, because it involves implicitly the size of the *order* to specify oscillation numbers; indeed the transparent for particles boundaries of the *order* make it possible to miss the particle. Being therefore irrelevant in experiments concerning particle trajectories, this type of non-local (analogous to crystal) detectors is however suitable for experiments, in which size is not important and might be regarded infinite as in diffraction or (two-slit) interference.

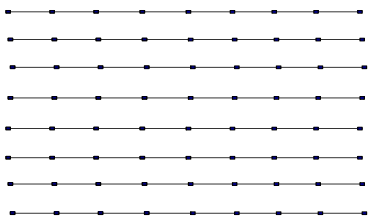

Fig.1 A uniform *order*.

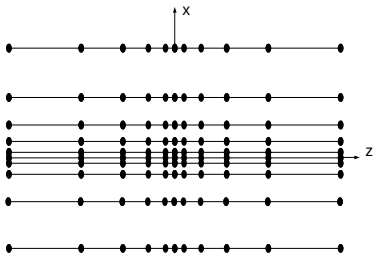

Fig.2 A non-uniform *order* keeping a particle inside.

An *order* relevant for trajectory measurements must therefore be limited in all directions still possessing the boundaries sealed for particles (Fig.2). Let its outermost intervals between the columns be covered by only one TSS oscillation, the number of oscillations increasing then toward the center of the *order* according to some law ([3]). The innermost interval with N oscillations corresponds to the scarcely detectable presence of a particle in the *order*. In the conventional terms, this particle should have some smallest momentum mv, with its mass m and velocity v. The particle will be detected there for sure, provided it moves faster than v

Since in the conventional formulation with the Planck constant h, $mv\sim h$, this relation defines the correspondence of the conventional units with our non-dimensional variable $n\leq N$ via the Compton wavelength $\lambda_c=h/mc$. In our analysis carried out here in conventional terms for the sake of visual clarity, we use λ_c as the measurement unit representing the fact of detecting the electron.

In the conventional scheme the signal from the "material point" detector gives the position of the body there with the probability 1. Similarly, the probability of the particle to be found inside the *order* must equal 1, provided some of its bodies give signals; therefore, the probability for the contact of the particle with any of identical bodies within a line or column of the *order* should be N^{-1} Unlike measurements with the uniform *order*, even a single contact of the particle doesn't determine now the momentum of a particle with respect to the *order* this contact occurs with, so now both position and momentum of the particle become related by the uncertainty condition.

In the approximation of trajectories with linked chains ([2],[3]), particles should be replaced with containing them *orders*, moving along the same directions. Then only the number of columns k crossed by the particle in this direction is important, and the probability to find the particle in these columns is k/N. In a link of the chain approximating a trajectory ([3]), with which acceleration of the particle is being determined, only the center of the *order* takes part, hence the particle's position inside it enters the link only with some probability. This is the uncertainty principle in our non-local scheme. In the following, parts of the uniform *order* will approximate the central region of the non-uniform one, and we will use conventional terms clearly interpretable in the TSS oscillation language.

Suppose now that along with TSS oscillations this *order* is filled with a linear polarized in x-direction plane electromagnetic (EM) wave pulse propagating in z-direction. Let the (now charged) particle, e.g., an electron move inside the *order*, which is at rest, the electron being further on accelerated by this EM pulse having some limited spatial volume. It is this situation that reveals electromagnetism via its action on motion of charged bodies.

Unlike typical cases of accelerating electrons by <u>given</u> EM wave (see, for example, [4] and references therein), we consider single photon annihilation, in which all the energy of the wave is exhausted in its interaction with the electron. It is well known, that this is impossible in free space. Indeed, the initial EM pulse with energy $W_{\omega 0}$ has the momentum $W_{\omega 0}/c$, and momentum conservation fixes the momentum of the electron as $p_e=W_{\omega 0}/c$ and the energy (for a small velocity) as $p_e^2/2m$, which is only the small $(W_{\omega 0}/2mc^2)$ part of the initial $W_{\omega 0}$ of the EM pulse. (Similar situation for any velocity is well known [1[.) However inside the *order*, scattering of the electron on the detector's bodies serves as a 'third body' to satisfy both momentum and energy conservation. Let us consider some sufficiently small central part of the non-uniform *order* (Fig.2) to be approximated with the uniform *order* (Fig.1), which, in conventional terms, consists of cells with the size λ_c. .The plane wave pulse polarized in x-direction and filling a volume V of this *order* with its Pointing vector in z-direction has initial energy density ($E=B$): $W_{\omega 0}=E^2/4\pi$. The electron with the charge e and mass m is initially at rest at the center of the *order*. When the head of the pulse enters the first central cell of the *order* the electron starts oscillating along the x-axis with the velocity $v_x=(eE/m\omega)\cos\omega t$ and moves along z-axis with the velocity $v_z=[(eE/m\omega)\cos\omega t]v_x/c$ (neglecting the term of v_z/c order in v_x).

If no scattering were there, the x-coordinate of the electron would reach over the half-period of the wave its maximum $\frac{1}{2}eE/m\omega^2$. Starting with the EM pulse head, elastically scattered on the heavy bodies of the *order* electron changes only the direction of its velocity and over S (many) periods of the pulse this random process is symmetrical around the x-axis. Hence it has no contribution to the momentum of the electron in z-direction, which comes solely from the average value of v_x given B. Transverse to the x-axis component of the electron velocity doesn't return its energy back to the wave over the whole cycle to be therefore responsible for its losses. The energy loss of the EM pulse due to this scattering dominates the total decrement in W_ω, whereas in the absence of this loss the only source of losses would be due to longitudinal acceleration of the electron: Were the phase of B with respect to E equal $\pi/2$ (no propagation) the kinetic energy of the oscillating electron would be returned to the wave. The electron-wave interaction losses come also from scattering, that generates additional set of random velocities around the z-axis, however this secondary effect on the total energy is small as compared to the direct scattering, which is multiple over all S periods λ/c of the EM pulse, and it might be decreased, if needed, by varying the inter-column distribution in z-direction.

The electron is accelerated first by *E*, neglecting the *B*-term (small as *v*/c*)*:

$$dv_x/dt \approx (e/m)E\sin(\omega t - kz) \qquad (1a),$$

and then rotated by *B* to give:

$$dv_z/dt=(e/m)(v_x/c)B\sin(\omega t - kz) \qquad (1b)$$

On average, the energy of the wave after its interaction with radial motion of the scattering electron is:

$$W_\omega = W_{\omega 0} - W_e; \qquad (2a)$$

$$W_{\omega 0} = \tfrac{1}{4}E^2(M\lambda_c)^2\lambda S; \qquad (2b)$$

$$W_e = \tfrac{1}{2}m2(eE/m\omega)^2 S - eE(M\lambda_c)S = (1/4\pi^2)E^2 r_e\lambda^2 S - eE(M\lambda_c)S \qquad (2c)$$

where M is the mean number of the *order* lines over which the electron scatters on the angle about $\pi/2$; r_e is the classical electron radius; λ is the wave length. The cylinder-shaped wave radius is of the order $M\lambda_c$.

In the absence of scattering the relevant wave radius should be $> \tfrac{1}{2}eE/m\omega^2$; First term in (2) stands for this range, whereas the second accounts for the part of electron energy returned to the wave. The difference gives the corresponding decrease in the wave energy, another part of which comes from acceleration of the electron along the Pointing vector, i.e. in z-direction.

According to (1b) the mean value of v_z is:

$$v_z = (2eE/mc)(M\lambda_c)S \qquad (3)$$

and this part of energy to be further subtracted from $W_{\omega 0}$ is:

$$\tfrac{1}{2}mv_z^2 = 2r_eE^2(M\lambda_c)^2S^2 \qquad (4)$$

Then momentum conservation for complete annihilation of the initial wave in its interaction with the electron $W_{\omega 0}/c = mv_z$ gives:

$$S = \{\tfrac{1}{4}\lambda[1 - r_e\lambda/\pi^2(M\lambda_c)^2] - e/E(M\lambda_c)\}/2r_e \qquad (5)$$

With (2b) and (5):

$$W_{\omega 0} = \tfrac{1}{4}E^2(M\lambda_c)^2\lambda\{\tfrac{1}{4}\lambda[(1 - r_e\lambda/\pi^2(M\lambda_c)^2] - e/(M\lambda_c)E\}/2r_e \qquad (6)$$

Upon varying E and/or M, we obtain different values of $W_{\omega 0}$. It is expected that wave-electron interaction should be effective, provided the own field of the electron e/r^2 will be comparable with that of the wave. In particular, choosing $E = 2^3e/M\lambda^2$ and substituting this value of E in (6), we obtain:

$$W_{\omega 0} = mc^2(\lambda_c^2/\lambda^2)\{2(\lambda_c^2/\lambda^2)[1 - r_e\lambda/\pi^2(M\lambda_c)^2] + \lambda/\lambda_c\} \qquad (7)$$

For typical values of $\lambda > 10^{-9}$cm in current experiments, (7) should be reduced to $W_{\omega 0} = mc^2\lambda_c/\lambda = \hbar\omega$, i.e., to the Compton-Einstein formula.

With the chosen E and similar approximation (5) becomes:

$$S = \lambda^2/16r_e\lambda_c \qquad (8a)$$

$$L = S\lambda = \lambda^3/16r_e\lambda_c \qquad (8b)$$

In the representation of trajectories via *orders*, L is the length of the EM pulse corresponding to a λ-photon. As an example, for λ about 10^{-9}cm, L is about 10^{-6}cm, hence self-interference experiments should use interferometers of appropriate size.

The presented measurement procedure starts with mere detecting the fact of presence of a particle inside the *order*. In conventional terms this fact is determined via λ_c, whereas in TSS variables it corresponds to maximal oscillation numbers within *orders*, required for this fact to be stated unambiguously. Contrary to

standard quantum theory, no wave-particle duality is needed with non-local detectors, since probability is introduced now without intermediate "wave function", and regular structures of appropriate detectors are responsible for wave-like behavior in interference or diffraction all of their own. Also entanglement (the EPR 'gedanken' experiment) naturally involves extended detectors.

Complete regularity of detectors (fig.1) makes it possible to split probability distributions into complex wave functions of quantum mechanics, just like the usual wave equation as directly defined with TSS [3] can be split into anti-symmetric (in their complex tensor form) Maxwell equations. This anti-symmetry, in turn, results from conservation of TSS oscillations ratios under any allowed field ([3],[5]).

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