Is indivisible single photon really essential for quantum communications, computing and encryption?

Contribution 1

A. F. KRACKLAUER

The general topic of this session is the question: what is a photon? An answer to this question directly feeds the answer to a sub-question, specifically: is the current understanding of the answer to first question, namely: the photon as corpuscle, a necessary condition for successful quantum computing? Both issues are intimately related; any answer to the first implies an answer to the second.

"Photon" is the name of a paradigm for the interaction of charged particles. So, in turn, what are paradigms in Physics? I suggest, as a practical matter, they are a collection of words, images and algorithms to assist in thinking about physical phenomena. They are conceptual tools for formulating a theory of the phenomenon of interest. It is useful to recall that a theory in science is basically an attempt to formulate a logical structure, for which Euclidean Geometry is the ideal prototype, with one striking difference: the input and output is to be related the "real exterior world," i.e., the inputs and outputs should be as close as possible to laboratory observables. (While there are many serious pertinent philosophical, and lexicographical, issues connected with these generalities; none are the point of interest here.)

What is not to be overlooked, is that, the central content of a theory, i.e., what comes after the inputs and before the outputs, is a *logical* structure. It is to be free of error or arbitrariness. In the physical sciences, this means that it is to be at least mathematically accurate and self consistent.

Now, at this point in the history of the development of a paradigm for the interaction of charged particles three paradigms have been put forth: waves, corpuscles and, very much less frequently, direct interaction. These paradigms are taken as working models for the interior of the theory of the electromagnetic interaction. As outlined above, their utility or success depends on two features: logical integrity and the extent to which their outputs sensibly correspond to laboratory observables.

The latter feature is very complex. Much of the detailed phenomena of the interaction of charged particles cannot be isolated and correlated with individual charged particles, but are many-body effects. Others are at such a small scale that they are not directly observable, but only inferable at the end of a sometimes very long chain of deductions. Almost always, a great deal of interpretation is required. This situation opens up much playing room for dispute and contention.

On the other hand, regarding the logical structure from which outputs are extracted, there are formal, sometimes quite abstract, criteria that are beyond dispute and contention. One such criterion, is that the theory in the end must result in mathematically well posed equations of motion for charged particles. This is a consequence of the fact that even a field theoretic paradigm (also known as: a *wave* theory of electromagnetism) is predicated on the existence of particles, either as the charge carries constituting the source currents input into Maxwell's equations (which are laboratory observables), or as the test charge needed to sample field strengths (as involved in the Lorentz force law – also an observable output). Specifically, in the end it is only the motion of charged particles that is observable and must be logically and accurately described.

This test in *not* met by either the wave theory or the corpuscular theory for multiple *interacting* charged particles. Maxwell's wave theory yields equations of motion only for a single charged test particle bathed in exterior fields for which source charges are not subject to the back action from the test charge. Corpuscular theories, even in their hybrid variant provided by quantum electrodynamics, are stymied at the same point, and in fact have very little to say about individual charged particles. There is no covariant system of coupled wave equations for interacting particles. The quantum theory of *individual* interacting systems of particles is vexed by many other technical questions and can be taken as essentially incomplete.

The Nature of Light: What are Photons? III, edited by Chandrasekhar Roychoudhuri,
Al F. Kracklauer, Andrei Yu. Khrennikov, Proc. of SPIE Vol. 7421, 74210Y · © 2009 SPIE
CCC code: 0277-786X/09/$18 · doi: 10.1117/12.845557

This writer, on the other hand, finds that the theory of direct interaction *on the light cone* (vice instantaneous, as in Newtonian gravitation) does lead to a set of well posed equations of motion for interacting charged particles[1]. It involves terms of the form of the Lienard-Wiechert potentials and the Lorentz force law, both of which (as outputs of the algorithm) have been verified "in the laboratory." In short, at this point in history, this paradigm suffers the fewest objections of principle and, therefore, is arguably the optimal paradigm for the electromagnetic interaction (although still lacking a fully quantized version).

Additionally, regarding consequences of the choice of paradigm for the second question, this writer notes that the potential advantages credited to quantum computing seem to derive from the mathematical nature of the Schrödinger equation, namely its character as a hyperbolic differential equation for the which the solution space is a Hilbert space, i.e., its elements are suitable for Fourier analysis. This would seem to imply that these advantages, if they exist and are exploitable at all, should also be available for any hyperbolic differential equation and at any scale. One possible consequence then would be that the "quantum algorithms" would not need atomic scale devices on which to run, but might be executable on macroscopic devices that are substantially easier to fabricate.

The standard objection to this supposition, that only the Schrödinger equation results in "entangled" states, has been repeatedly addressed by this (and other) writers with the rebuttal, that entanglement is either just ordinary correlation or utterly misconstrued on account of a fundamental error in applying probability concepts - an error first discussed by Edwin Jaynes[2].

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Contribution 2

C. Rangacharyulu

Physics, as an enterprise of scientific inquiry, has two facets: *a)* application-oriented research influencing the technological advances for the good or bad of the humanity and *b)* basic science attempting to unravel the mysteries of dynamics of physical universe. It can justifiably claim several crowing achievements of the past and present-day technologies. One may even venture to say that physics is at the heart of all science and technology as biological and medical sciences, amongst many others, apply micro- and nano-technologies in the modern era. The miniaturization of computer systems owes it to the discovery of giant magneto resistance twenty years ago. The list goes on.

However, we have to question if physics has been successful in the self-assigned tasks of offering a coherent, logically consistent description of the dynamics of physical universe in terms of the fundamental constituents and interactions among them. The answer is not in affirmative. One may state that a major accomplishment of the 20th century particle physics was to establish that the principle of reductionism failed. One might safely conclude that the rise of quark model brought forth the fall of reductionism, as the elusive quarks have been finally condemned to be confined in the hadronic matter, revealing their existence only through jets of hadronic matters in high energy collisions or via the excitation spectrum of nucleons and mesons. The characterization of physical vacuum as a medium filled with matter, the description of nucleons as composed of three valence quarks and an infinite number of sea quarks and the need to perceive the entire physical universe as a super-conductor support the above assertion.

Physics textbooks and physicists proclaim that Einsteinian relativity is an extension of Galelian relativity to high velocities and that it reduces to the latter at low-speeds. Nothing can be far off from logical rigor than this statement. It is correct to state that Einstein-Lorentz transformations tend to Galelian relativity as mathematical approximations at low velocities. There are irreconcilable differences in the concepts of space-time in the frame works of these two theories of relativity. The Galelian relativity calls for an absolute time and implies absolute space. Einsteinian theory insists that both time and space are relative and it denies absolute space-time concepts. Thus, it is erroneous to conclude that Einstenian 4-dimensional space-time collapses to 3-dimensional space and one-dimensional time at low speeds and renders space and time absolute.

Just as Newtonian-Galelian relativity serves as operational definition to classical physics at small velocities, Einsteinian relativity, with a change in physical world-view, provides a mathematical apparatus to describe the phenomena encompassing the full spectrum of observable phenomena at velocities both high and low. We must, however, be concerned that it comes at a price. It is at the expense of elevating time, a dependent observable, to the status of spatial coordinates. Clearly, there is a logical inconsistency here. The time measurement requires that the spatial orientation of the observable phenomena be specified while spatial coordinate assignment does not necessarily involve knowledge of time.

The quantum computing communities strive to develop a powerful computer, quantum cryptography and teleportation. They may achieve it, but the success may not depend on our understanding of quantum entanglement. It is because the structure wave functions and models they build are what one would call as "mixed ensembles" amenable to density matrix formalism rather than the inseparable entangled components. In an entangled state, the system is a coherent superposition of the amplitudes of possible configurations, all of which yield identical results for any physics observable. It is only when they are disentangled, one can gain knowledge of the amplitudes of two partners by measuring one of them and appealing to the conservation principles. The mixed ensembles are states of finite degeneracy, which may be lifted by the external influences such as electromagnetic fields. They are incoherent intensity components of an ensemble of particles. The great debate between Einstein and Bohr concerned the entanglement and not the mixed ensembles. It is essential that quantum information scientists bear in mind this distinction to be able to achieve correct interpretations of the experimental outcomes.

On the question of one or two photon interference, the physicists' reasoning should suggest that no such interference occurs. The question posed is how is it that two coherent photon beams, producing an interference pattern on a screen, propagate at other points in space as if the interference does not occur. We may restate this as follows. In a Young's double slit interference experiment, if we remove the screen, the intensity distributions at points behind the original position of the screen will appear as the two non-interfering photon distribution. Do photons interact with each other in the absence of an intervening medium such as the screen? If yes, how is it that would they reappear unimpeded at some other point in space? If no, where does the influence of medium appear in the mathematical formulations?

While the classical physics provides a satisfactory phenomenological description of the observations, the quantum electrodynamics might, albeit inadvertently, give an answer to this question. The intensity distribution in the interference may be attributed to the screen-photon interactions where the post-interaction photons are distinct from the incident ones. In quantum electrodynamics, quanta do not propagate. The motion is a result of creation and destruction operators. That is to say, the traversal of an object from a point "A" to another point "B" is described as destruction of the object at point "A" by an annihilation operator, say a(A), and creation of its replica at point "B", by a creation operator $a^{+}(B)$. When fields of two photons are incident at a point on the screen, the observed intensity is due to the coherent summation of the two fields. In the absence of a screen, there is no material medium and no interaction of a photon with a field. It is a mute point to argue if the photon fields exist in the absence of an interacting medium since every measurement apparatus comprises of an interacting medium. We might visualize photon propagation or that of any quantum as recurrent creation and destruction processes. From this discussion, we see that the quantum field theories rely on the existence of ether or its substitute without which quantum electrodynamics cannot propagate the photons or electromagnetic radiation. Quantum field theories are generalization of this statement to all quanta.

Personally, I cannot imagine that the dynamics of the physical universe cease to exist if human civilization or our gadgets vanish. While observer independent reality exists, it is not accessible without an observer. As we attempt to describe phenomena, we allowed ourselves a lot of flexibility in the physical concepts. Just to name one, the concept of virtual quanta, permitting energy uncertainties within the limits of Heisenberg's principle is a source of ambiguities. It is imperative that physics must live up to the expectations of it as hardcore science and maintain the highest standards of logical rigor. We seem to have lost this as we chase the deeper secrets of nature, but it is never too late to reassess the framework.

Contribution 3

Prof. Chandrasekhar Roychoudhuri
University of Connecticut and Femto Macro Continuum, Storrs, CT, USA

My position is based upon two observations that are accepted by quantum mechanics at a fundamental level, although, usually ignored during implementation for convenience of staying within the strong influence of the Copenhagen Interpretation. (i) First, let me quote Dirac's famous statement, "Interference between different photons never occurs", which correctly captured the general reality that light beams do not interfere by themselves to create energy re-distribution (fringes) in the absence of light-matter interaction. Photons are Bosons and they can occupy the same space at the same moment while passing through each other completely unperturbed. This obvious reality was also missed by classical physics. Perhaps, Dirac failed to over-ride the classical cultural belief system that "light interferes with light" and hence wrote another sentence, "Each photon then interferes only with itself", preceding the previous quotation given above. Of course, self-interference and appearance and dis-appearance of any stable elementary particle from certain space and temporal position to create fringes, without undergoing any interaction, is a gross violation of the very conceptual and mathematical foundation of physics. All registered superposition phenomenon between light beams become manifests through some measurable transformation experienced by a detector. This brings us to our second point. (ii) We cannot measure anything that is interaction-free and force-free [1]. In physical experiments, we measure some transformations between the interactants. All such transformations require some energy exchange, which must be guided by one of the allowed four forces. Since, all forces have finite ranges, all measurable transformations experienced by the interactants are bound to be *local* in the sense that they must be within the sphere of influence of each other [2]. In this world there is no force-free, interaction-free, or energy-exchange-free transformation that we can measure using our real physical instruments. Otherwise, our mathematical equations, which represent strict causal and logical relationship between different interactants or different fields, could not have been so successful in predicting our measurement results.

Let us now "jump into" the following conclusion that will be clarified further in later paragraphs. Those engineering designs, meant for quantum communication, computing and encryption, which literally require generation, modulation, complex-system-propagation and detection of the same indivisible single photon, will be impossible to realize in practice. This is especially true for photons in the visible and infrared range due to diffractive spreading of light beams. Since diffractive spreading is inversely proportional to the frequency, high energy individual gamma photons can be tracked. But we do not have such flexibility with visible photons, especially, considering all the current technologies related to generation, diffractive-propagation and detection of visible photons.

Let us quickly assess the indivisibility of photons [3]. This is a myth even in quantum optics. Light propagates through the cosmic medium, following universal diffraction phenomenon for EM waves. This is well validated through the use of the diffraction theory (i) to design and analyze image formation in macro domain like Hubble telescope, and (ii) to design practical complex nano-photonc integrated optoelectronics in the nano domain. So photons are all prone to energy divisibility as they interact with other material particles or are obstructed by some apertures [4]. While inverse proportionality of diffractive divergence to frequency allows gamma photons to preserve their strong particle-like nature, their divisibility is obvious from their tracks in volume-scintillation detectors as they keep on loosing their energy in a series of discrete interactions. The divisibility of X-ray photons is obvious from the classic Compton scattering where every scattering from an electron, the original photon gives up a part of its energy and comes out as a lower frequency photon. The divisibility of visible photons is obvious from nonlinear optical processes like parametric down conversion. Summability of visible photons is obvious from nonlinear frequency summing [5] and two-photon fluorescence processes. Of course, QED also claims that the original photon in all interaction processes is first absorbed completely and then a new indivisible photon is emitted. Physicists must accept a common conceptual premise so debates can produce productive and logical outcomes.

The next important criterion used in quantum optics for quantum computing like applications, which use interferometers, is *entanglement* of different photons produced by a beam-splitter, or by a parametric down-converter. We believe that the *entanglement* characteristic should be reserved for those states that are literally *entangled* through an operating quantum mechanical force. Consider the example of quantum states of atoms A and B bound inside a large molecule. Clearly, the rotational and vibrational states of A can be influenced by tinkering with those of B. These quantum states are truly *entangled*, because they influence each other through the complex electromagnetic binding force that holds the molecule together. If A and B are released by delivering a force greater than their binding energies, they will be released. After release, A and B. will carry on complementary properties based on all the conservation laws.

However, they are no longer *entangled* to each other provided they are far from each others direct influence of electromagnetic forces.

This logic is even more dramatic for a photon pair production in the visible range, whether one uses the cascade-emission or the down-conversion process. The photon pair will carry on complimentary physical properties like polarization, frequency etc., enforced by conservation laws during the quantum mechanical process of emission (light-matter interaction). However, they will not be *entangled* to each other in any physical sense, because there is no influencing photon-photon interaction force between them when they are freely flying away with velocity c or c/n.

Let us split a collimated laser beam into two new spatially independent beams of well defined beam-waist, either with the original frequency using a beam-splitter, or with a new frequency using a frequency down-conversion system. Let these two beams be used in two independent interferometers on the same table, say, a Michelson and a Mach-Zehnder, to quantitatively measure the length of a meter-block and the refractive index of some material, respectively, using superposition fringe counts. We will derive accurate reproducible results from each interferometer, independent of the *parallel* existence of the other. Now, let us insert a tandem of laser energy absorbers in the original laser beam to reduce the photoelectric "click" counts from many billions to a few thousands per second. Will the results of the two interferometers become *entangled*? There is nothing magical about reducing the photoelectric "click" counts from very large to very low rates, unless the superposition phenomenon at very low light flux follows different physical law that we have not quantitatively articulated yet. Of, course, keeping track of the statistics of the counts become more difficult. [Note that the "click" counts are not single electrons. They constitute amplified current pulses carrying probably billions of electrons per pulse!]

The physical states of the *Schrodinger's Cat* as *dead* or *alive* do not become *entangled* simply by forcing the cat inside a closed chamber with radioactive trigger to release deadly poison inside. Radioactive particle emission from an excited nucleus is certainly a quantum mechanical statistical process; the pre-emission and the post-emission states of the radioactive nucleus are certainly related to each other or are *entangled* by the nuclear force. But, once released and far from the influence of the nuclear force of the parent nucleus, the emitted particle is no longer *entangled* with the parent. It is now a "classical" particle until it interacts with a new quantum entity to create new *entanglement* independent of the parent nucleus. The radioactive poison triggering device is totally a classical device although the timing of the trigger-event is statistically determined by the quantum mechanical nucleus. The *dead* or *alive* states of the Schrodinger's Cat are never entangled; they are classical states and are doubly removed from the quantum mechanical excited state of the original nucleus. It appears that Schrödinger's sarcasm was converted into real physics, followed by introduction of mysticism, like *interaction-free transformations*, *teleportation, production of multiple universes during every quantum transition, etc.,* into serious physics!

In summary, force-free, interaction-free, *entangled* photon-states do not exist in the real world. Besides, there is no photon-photon interaction that can *entangle* them! The continuously evolving universe, from macro to micro levels, is causal. This is the crucial reason why human constructed logical and causal mathematical equations are able to guide us to understand so much of this still-unknown but a magnificent cosmic system.

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Contribution 4

Juliana H. J. Brooks*
General Resonance LLC, Havre de Grace, MD, USA

ABSTRACT

The photon is neither the elementary quantum of light, nor is it indivisible. Hence the indivisible single photon *cannot* be essential for quantum communications, computing and encryption.

SUMMARY

Max Karl Planck sparked the entire quantum revolution in 1900-1901, with his famous black-body radiation work and Quantum Hypothesis (i.e., the idea that energy is quantized in small, equal amounts).[1] As part of that work, Planck assumed his quantum formula, E = h*v,* as a mathematical given.[†] A few years later, Albert Einstein used Planck's quantum relationship to explain the photoelectric effect, by suggesting that the energy of light is localized in space "*and can be absorbed or generated only as complete units*", which he called "light-quanta". In 1926, Gilbert Lewis suggested the name "photon" for Einstein's units or light-quanta. The photon was subsequently interpreted as an indivisible packet of light, whose energy is defined by Planck's quantum formula, $E = h\nu$.

Planck's quantum formula, however, is missing the variable for measurement time.[2] Planck had included measurement time as a variable in his earlier electromagnetic theories. In the late 1890's, however, Planck adopted Wilhelm Wien's mathematical procedure for converting time-based energy measurements into energy density values. Wien's mathematical process inadvertently fixed the measurement time at "one second", and caused the measurement time variable to be omitted from subsequent equations. Hence, Planck's subsequent quantum formula was missing the variable for measurement time. Restoring the variable produces Planck's original quantum relationship:

$$E = \tilde{h}\, \nu\, t \quad (1)$$

Closer inspection reveals that Planck's constant ("h") is actually an *energy* constant, and not an action constant, as long believed. Planck's *energy* constant ("$\tilde{h}$") is the mean energy of a single oscillation of light, 6.626 X 10^{-34} J/osc. The mean energy of a single wave or oscillation of light is constant, regardless of the light's frequency or wavelength. Thus, the *energy* of a single oscillation (i.e., cycle or wavelength) of light is invariant under a shift in time or space. The energy of light is conserved, rendering the single oscillation of light the true elementary particle of light.

Although the photon has long been held to be the elementary quantum of light, that understanding must be re-examined. It appears to have arisen from limitations in Planck's abbreviated quantum formula. The hidden time variable, missing from Planck's condensed quantum formula, was fixed at a value of one second. Use of the condensed quantum formula to calculate photon energies, inadvertently defined the photon as an increment of light of one second's duration. An arbitrary, one second increment of energy cannot be a truly indivisible and elementary particle of nature. Dissatisfaction with prior interpretations of the "photon" as an indivisible and elementary quantum of light appear to have been well-founded.

If the photon is neither the elementary quantum of light nor indivisible, it seems apparent that it cannot be essential for quantum communications, computing or encryption. Numerous theoretical quantum concepts have been developed however, to explain interactions of the illusory photon with quantum devices. These concepts are based in large part on a process referred to as quantum entanglement, which is said to be essential for quantum communications, computing and encryption. If the photon is not an indivisible or elementary quantum of light, what then is this entanglement that appears to be so vital? Classically, entanglement is said to occur when the energy of a "photon" is absorbed and spread amongst several atoms or molecules in a quantum device. An entangled state of the atoms or

* Juliana H. J. Brooks, General Resonance LLC, One Resonance Way, Havre de Grace, MD 21078, USA, Phone 410-939-2343, Email DrBrooks@GeneralResonance.com , Website www.GeneralResonance.com

† Where "E" is energy, "h" is Planck's *action* constant (i.e., energy x time), and "*v*" is frequency (i.e., oscillations/time).

molecules in the quantum system results.[3] If a photon is later emitted by the quantum system, it is thought to be produced by the same ensemble of atoms or molecules involved in the quantum state.

Although this classical interpretation of entanglement relies on a misunderstanding of photons, it never-the-less offers valuable insights into the true nature of light, entanglement and quantum processes. The classically defined "photon" is a time-based measurement of energy, consisting of many individual oscillations of light. Each individual oscillation is a "*complete unit*" of light, and each possesses a small quantum of energy. The photon then, is a collection or ensemble of light oscillations, which can act separately and individually as complete energy units of light. When this ensemble of individual light oscillations is absorbed by a quantum device, the individual oscillations can be spread amongst several atoms or molecules in the quantum device, each oscillation being absorbed as a complete unit by one atom or molecule. This absorption of oscillation energy can take place in different patterns or distributions amongst the various atoms or molecules in the detector. These differing patterns of energy distribution result in what are referred to as "entanglement" or different "quantum states". Likewise, when an ensemble of individual light oscillations are *emitted* by a device, that emission of light energy can occur from an "entangled" quantum state or energy distribution pattern amongst the various atoms or molecules. Hence, the quantum concept referred to as entanglement relies on the differing patterns of absorption, distribution and emission of the energy of individual oscillations of light.

This understanding of the single oscillation of light as a complete unit of energy which can be absorbed or emitted, reveals additional concepts important to quantum communications, computing and encryption.[5] The energy of a single oscillation of light is associated with a measurable wavelength in space. The longer the wavelength, the greater the distance over which the whole energy quantum is distributed in space. Imagine two individual oscillations (i.e., light waves) traveling at the speed of light towards a detector. One wave is a meter long, and the other wave is only a nanometer long (10^{-9} meters). Their leading edges are both the same distance from the detector, and since the waves are traveling at the same speed, their leading edges strike the detector at the same time. After the waves have traveled an additional nanometer, the entire quantum of energy of the nanometer wave has been absorbed by the detector (i.e., its trailing edge has also reached the detector). Most of the energy of the meter-long wave is still outside the detector, however, and its trailing edge is still almost a meter away. As it continues to travel at the speed of light, its trailing edge will eventually reach the detector as well. It will have taken a billion times longer for the complete energy unit of the meter-long wave to be absorbed by the detector, however, than for the nanometer wave.

In other words, while the speeds of the two waves are identical and their leading edges reach the detector at the same time, the total *energy quantum* of the shorter nanometer-length wave will be deposited in the detector much sooner that the *energy quantum* of the meter-long wave. The energy unit speed of the nanometer wave is much faster than the energy unit speed of the meter-long wave. Thus, the speed of light's complete *energy* unit is relative to its wavelength.[5]

The wave speed of light is constant, and conforms to the Lorentz transformation. The *energy* speed of light is infinitely variable, however, and conforms to the Galilean transformation.[‡] This unique aspect of light allows the transfer of oscillation-based information at supraluminal velocities, without violating the principles of special relativity.

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‡ $\tilde{c} = cN$, where "$\tilde{c}$" is the *energy* (unit) speed of light, "c" is the wave (classical) speed of light, and "N" is the number of sequential light oscillations in one unit timespace (t⊥s), i.e., one second ⊥ 300 million meters).

Contribution 5

John E. Carroll
Centre for Advanced Photonics and Electronics, Engineering Department, University of Cambridge,
9 JJ Thomson Avenue, Cambridge,CB3 0FA, UK

ABSTRACT

Most researchers can agree that entanglement is a key requirement for quantum computing and secure quantum communication systems. Whether *single* photons are essential for such systems remains unclear because both photons and entanglement are complex mathematical quantum concepts. One could wish for a more physical picture for example within a classical Maxwellian framework. Carroll and Beals [1] have put forward such a model for a photon-like packet that can suggest how photons obtain their variety of features: quantization, localization, coherence and entanglement. The model can also be extended, as suggested here, to consider photon clumps proposed by Panarella [2]. If such modeling has a sound basis then it seems possible that entangled single photons might be replaced with entangled coherent photon clumps for use with quantum computing and secure communications. The Carroll-Beals model assumes that all waves have some diffraction, forcing axial fields (E_{axial} and B_{axial}) to be non-zero alongside transverse fields ($\mathbf{E}_{\mathbf{transverse}}$ and $\mathbf{B}_{\mathbf{transverse}}$). A new solution of Maxwell's classical equations demonstrates that arbitrary modal patterns of transverse field can be helically modulated with a modulation moving at the group velocity. The transverse fields rotate with 'Distributed Spin Rotations'about every local axis. The frequency of this helical modulation may be quite different from the modal frequency. Classical causal retarded waves, but with one sign of helical rotation, are called *reference* waves. By reversing the helical rotation operation along with reversal of frequency *and* time, new *adjoint* waves are produced. These adjoint waves still have the same field patterns. Because both time and frequency are changed in sign, the adjoint waves propagate in phase with the reference waves. All *transverse* fields can then be trapped between nodes formed by the counter rotating helical waves (Fig.1). All *axial* fields can be trapped between nodes formed by a classical wavepacket formed from two frequencies. (Fig. 2). The Carroll-Beals model then combines a classical wave-packet with the new counter rotating helical modulation to form a closed packet where both transverse and axial fields are completely trapped between nodes. Quantisation of the helical modulation arises because the end nodes of the helical modulation must coincide with the end nodes of the classical two-frequency packet (Fig.3a). Quantisation of the energy arises from the quantised helical twist. The concept of the adjoint wave is analogous to Cramer's advanced wave [3] but here, just as any causal reference wave has a 'wave-front', so the time and frequency reversed adjoint wave has a 'wave-rear'. Any quantum packet is then envisaged as being trapped between the wave-rear of the adjoint wave and the wave-front of the reference wave (Fig. 4). The collapse of a quantum wave function is no longer an extended event that is difficult to comprehend but simply the collapse of a local overlap of the reference and adjoint waves. The adjoint wave, as outlined by Carroll and Beals, gives that additional degree of freedom that allows entanglement of photons. The measurement conditions at an output port help to determine the measurement outcome just as much as the excitation conditions at an input port. The "single photon" packet has 2 nodes for the axial fields and 4 nodes created by the counter rotating helical modulation of the transverse fields (Fig. 3a). A "two photon" clump can have *either* 3 axial field nodes with 7 transverse field nodes *or* 2 axial field nodes with 6 transverse field nodes (Fig. 3b,c). The model can be extended to N-photon coherent clumps with different numbers of axial and transverse nodes. Identical coherent clumps would have identical sets of nodes and frequencies. Entanglement, as explained in reference [2], depends on the adjoint waves where the direction of time is reversed. It is the boundary conditions at the measurement point that determine what adjoint waves are statistically available (see also caption for Fig.4). It is the adjoint waves that create entanglement. Given two *identical* coherent photon-clumps at the start, then this model suggests that entanglement could be gained in the same way as for a single photon pair. Interfering with a pair of identical single photons can be immediately detected in secure quantum communications but it is suggested that interfering with an identical pair of coherent photon clumps could also be detected so that security need not be compromised. However it must be admitted that suggesting that entangled identical coherent photon clumps can be envisaged is not the same as showing how such clumps may be practically generated. More work remains to be done.

Keywords: Photons, photon clumps Maxwell's equations, entanglement, quantum communications

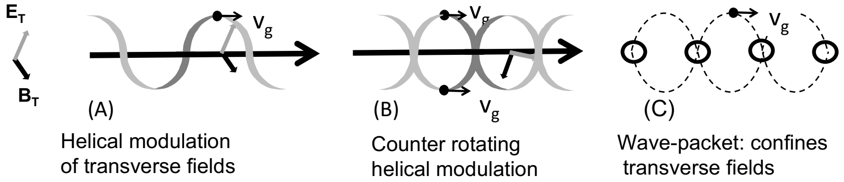

Fig. 1. Schematic of the envelope created by counter rotating helical modulations (Distributed Spin Rotations). (A) DSR for the transverse fields. (B) Counter-rotating DSR added to (A). (C) Effect of B creating an axial envelope for the transverse fields with no added spin or rotation (M = 3). Transverse fields fall to zero at the points labelled with bold **O**.

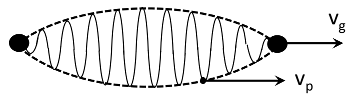

Fig. 2. Classic wave-packet determined by two beating frequencies. Axial fields can fall to zero at bold points.

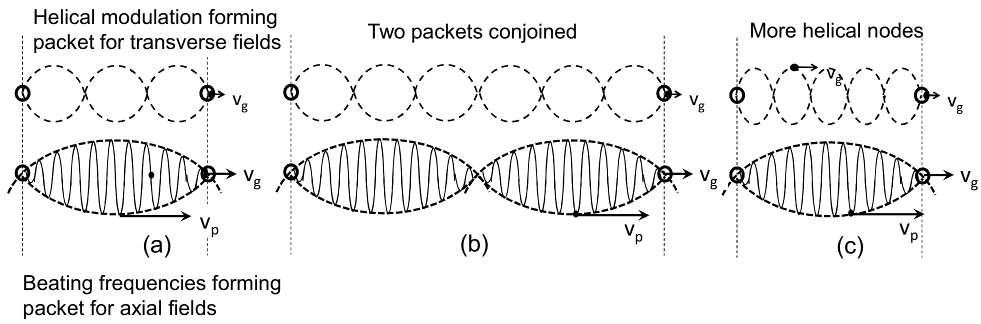

Fig.3 (a) Schematic of Maxwellian field model with single photon-like properties. The nodal interval for the transverse field envelope is determined from helical modulation of (2N+1) $\Delta\omega$ (N=1 here). The nodal interval for the axial field envelope is determined from $\Delta\omega$. (b) Concatenated two single photon-like packets: 2-photon 'clump'. Can be extended to N-photon clump. (c) Greater helical modulation gives more energy – "2-photon" clump. Can be extended.

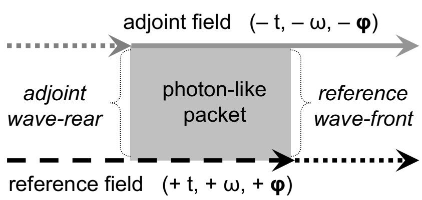

Fig. 4. Schematic of quantum packet trapped between the adjoint wave rear and the reference wave front. Collapse of quantum wave function is a collapse of the overlap of the causal reference field and the 'time and frequency' reversed adjoint field. Entanglement is created because boundary conditions on the adjoint field at the output can affect the measurement as much as boundary conditions on the reference field at the input and give extra degrees of freedom [2].

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Contribution 6

Andrei Khrennikov[a]

[a]International Center for Mathematical Modeling
in Physics and Cognitive Sciences,
University of Växjö, S-35195, Sweden

ABSTRACT

The wave-particle duality and completeness of quantum mechanics are criticised. A model of purely field reality is debated. Unified field theory as prequantum field theory is discussed.

Keywords: Wave-particle duality, completeness, prequantum field theory, unified field theory

The wave-particle duality is one of the main mysteries of quantum mechanics (QM). We remind the historical basis of this important philosophic principle. It is well known that Bohr formulated his principle of complementarity as a personal reaction on the impossibility to create a classical-like model describing individual micro systems. His psychical conditions were not especially good at that time. He understood that he should either recognize that he and his collaborators were not able to create a satisfactory model of microscopic processes or claim that creation of such a model is in principle impossible. He decided to save his Ego on the price of this extremely misleading principle. My personal opinion is that, since works of Lois De Broglie, it became more or less evident that one might try to proceed towards purely wave model of micro-reality. Similar views were advertised in first papers of Schrödinger. Einstein also worked a lot towards elimination of particles from the description of physical reality in favor of the use of fields.

During last years I developed a purely field model of micro processes, so called prequantum classical statistical field theory (PCSFT). In this model not only photon, but any of so called quantum particles is described by classical field. The main problem of such an approach is to explain functioning of detectors which detect (as it is claimed by conventional QM) particles. An interesting step towards a purely classical field model of detection of photons in Bell's type experiments was recently done by my graduate student G. Adenier who obtained quantum statistics of counts by considering a model of detector interacting with classical electromagnetic field. The crucial point is the presence of thresholds in all modern detectors used for Bell's type experiments.

We recall that it is really possible to proceed very far by using so called *semiclassical approach.* By the latter electromagnetic field is not quantized at all. It is a classical random field. Quantization is the result of "quantization of matter". Thus electrons, protons, neutrons should be described by QM, but, instead of photons, it is possible to work with classical pulses. Some founders of QM, e.g., Lande and Lamb, debated such a viewpoint during many years. For example, Lamb[1] wrote: *" It is high time to give up the use of the word "photon", and of a bad concept which will shortly be a century old. Radiation does not consists of particles ..."*

The semiclassical approach simplifies essentially some important problems in quantum optics.

I can mention main tasks justify the anti-photon approach:

1). Creation of detailed models of functioning of detectors threshold detectors interacting with classical fields !

2). Realization of basic quantum experiments with detectors which are not based on threshold-scheme, especially microcalorimeter detectors!

In the two slit experiment two detectors can be placed opposite to corresponding slits. But only one clicks! Never two do this simultaneously (for single photon source). Of course, the single photon regime is an idealization.

E-mail: Andrei.Khrennikov@vxu.se

In real experiments double clicks are always present. The most famous experiment of this type has been done by Grangier. It is commonly assumed that this experiment confirmed photon concept. However, my student G. Adenier showed that by using threshold detectors interacting with classical light one can simulate results of Grangier experiment!

Tasks:

1). Realization of new and very precise two slit experiments with detection in the single photon regime;

2). Realization of such experiments even for microcalorimeter detectors.

My model, PCSFT, also implies continuous classical field type entities and not corpuscular photons. However, in general my position differs essentially from the position of Lande, Lamb and other adherents of the semiclassical approach. They sharply distinguished electromagnetic radiation which is continuous and classical from quantum matter, e.g., electrons. In PSCFT quantum matter is represented by continuous classical fields, e.g., electronic radiation field or neutronic radiation field.

Prequantum fields corresponding to various quantum particles can be considered as forms of a single prequantum field. This can be considered as a step towards *prequantum unified field theory.* In this framework it may be natural to assume that fluctuations of the prequantum field are performed on the Planck scale of space-time.

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