Wave Particle Unity and a Physically Realist Interpretation of Light

by

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Abstract

This paper sketches a program towards giving a physically realist model of the photon in terms of properties of the electromagnetic field. It is both shown how to rework traditional wave and particle concepts so as to have a unified concept and how parallel electromagnetic fields can be associated with each charged particle. An account of both light propagation and of interactions with matter is sketched. A suggestion is made as to how the account may be able to explain EPR correlations in the case of polarization entanglement. A possible empirical test is also discussed.

Key Words: Wave Particle Unity; Bell States; Entanglement; Advanced Wave

I hold that the key to understanding quantum properties of light involves transforming the traditional concept of the electromagnetic field. Instead of holding that an electric field is a single field created by a summation of effects from different charges, I hold that the overall field is comprised of a series of parallel three-dimensional subspaces each associated with a charged source particle. Mathematically, the two approaches are the same though, it is just that the summations occur at different locations. Under the traditional account, the strength of the E field at a given location is proportional to a vector summation of the effects from each charge q and the force at this location is proportional to the strength of the field there. In contrast, under my account the strength of each field is a function of the source particle charge and distance from it, and the resultant force at a given location is proportional to a vector summation of the effects from each of the fields at that location. Hence, as in the first case, the resultant force is a function of a summation of the charges and the distances from them.

I identify particles with waves, which I will call here 'wave-particles.' In the case of light (where the waves are electromagnetic fields and the particles are photons), I am thus identifying photons with oscillating electromagnetic fields. On the surface this position may appear to be paradoxical, since, as traditionally conceived, particles possess precise locations (an extreme version of which is the point particle) and waves are conceived as being spread out over all physically possible paths. Traditionally waves are conceived as being undulations traveling over a medium where the medium does not travel, while particles travel through space. Also, waves are conceived as being able to pass by each other without any mutual effects, while in the extreme traditional conception particles are conceived as being impenetrable. Also, in the extreme traditional conception particles are conceived as being indivisible while waves break up into wavelets when they reach a barrier. I believe that the following moves to some extent alleviate threse traditional difficulties.

First, I locate the wave-particles in separate parallel three-dimensional subspaces in an overall four-dimensional space (not Minkowski spacetime since all of the dimensions are just spatial and not also temporal). I thus hold that the wave-particles are able to 'glide by' each other without affecting each other until they reach a potential absorber. For purposes of this exposition, potential absorbers are taken as being finitely-sized four-dimensional entities, and thus impinging on each of the subspaces at a given location. Secondly, I believe that a 'traveling wave' which consists of oscillating 'matter' traveling independently of a medium is at least coherent, although for the purposes of this paper I will not make a stand on whether light consists of such a wave. Also, I do not hold that it is typically the numerically identical photon which is both emitted and later absorbed. Instead, as I will be elaborating on shortly, I hold that photons are routinely broken up into what I term 'partial photons' and then recombined in a discrete manner in the absorption process.

In the photon emission process, I hold that a photon number state (Fock state) is created in the field associated with the emitting particle. It will be propagated at the speed of light c in this field until complications set in as with elastic scattering and reflections. It might appear that there is a conflict here with traditional accounts of quantum electrodynamics (QED) since according to traditional accounts (1) where the vector potential is quantized, the electric field vanishes for photon number states. However, this is only the average value of the field, and thus there can still be fluctuations on either side of the value. It can also be noted that the average intensity of the field (the square of the field strength) will remain positive. I should also note that for the purposes of this exposition, the electromagnetic fields associated with light will be postulated to possess both vector (force) and scalar (energy) aspects; the two aspects being related, in the case of the plane electromagnetic wave, by the energy density of the wave $\mathbf{E}^2 + \mathbf{B}^2$. I also postulate that these fields are modulated at the rate associated with energy fields;i. e. an inverse square rate.

I hold then that light consists of spherical waves oscillating perpendicular to the line of propagation. The **E** wave and the **B** wave will be in adjacent subspaces oscillating on orthogonal axes, with the frequency of oscillation corresponding to ν, the frequency of the corresponding wavelength of light. Angles of polarization here will be determined by the axes of rotation of the **E** waves. The rotational waves will be defined as having a radial propagation of c and a transverse propagation in the form of an oscillating rotational wave with a maximum speed of c. They will also be defined as being rotationally perpendicular to each other and so as to be out of phase by π. The equations for the effective angular velocities $\mathbf{\Omega_1}$ and $\mathbf{\Omega_2}$ for these two oscillating fields can thus be defined as

$$\mathbf{\Omega_1} = (c/r)\mathbf{a}\cos(\omega t) \quad [1]$$

and

$$\mathbf{\Omega_2} = (c/r)\mathbf{b}\sin(\omega t) \quad [2]$$

where r is the radius from the source particle at time t, ω is the angular frequency of the light wave, and **a** and **b** are orthogonal radial unit vectors centered at the source particle and aligned with the axes of rotation respectively of the **E** and **B** fields.

I will now discuss a linkage between these rotational waves and probability amplitudes. I will deal first with the case where there is just a single path linking the particles emitting and subsequently absorbing the photon, and then will deal with the multiple path case. In the single path case I wish to introduce two probability amplitudes Φ_1 and Φ_2. These correspond to the real (cosine) and "imaginary" (sine) terms of the Euler identity expansion for the probability amplitude (using the Feynman path integral approach) of a physically possible path between two points

$$\Phi = e^{iS/h} = \cos(S/h) + i \sin (S/h) \qquad [3]$$

where S is the action between the points, h is Planck's constant. and Φ is the probability amplitude for the path. It should be emphasized that only paths close to the classical paths actually contribute to the amplitudes and thus that the crazy ones cancel out, as Feynman notes. (2, 3) I also wish to construe these amplitudes realistically in terms of properties of the foregoing rotational waves $\mathbf{\Omega_1}$ and $\mathbf{\Omega}_{\mathbf{1}}$. In particular, Φ_1 and Φ_2 can be defined as follows:

$$\Phi_1 = A(\omega^{1/2}/c^{1/2}r)\cos(\omega t) \qquad [4]$$

$$\Phi_2 = A(\omega^{1/2}/c^{1/2}r)\sin(\omega t) \qquad [5]$$

where r is the distance from the source particle, and $A=(c/4\pi\omega\Delta r)^{1/2}$ is a normalization factor for a wave packet emitted between times t_1 and t_2 traveling at c over a finite distance to a potential absorber. The width of the wave packet is thus $\Delta r = c(t_1 - t_2)$. I will interpret these amplitudes physically as corresponding to the E and B force fields. The probability P for a photon being absorbed is traditionally given by multiplying a probability amplitude by its complex conjugate. In my notation this corresponds to summing the squares of Φ_1 and Φ_2. Thus, the probability density for absorption is given by:

$$P = \Psi\Psi^* = \Phi_1^2 + \Phi_2^2 = A^2(\omega/cr^2)\cos^2(\omega t) + A^2(\omega/cr^2)\sin^2(\omega t) \ [cm^{-3}] \qquad [6]$$

It can be noted that the while the magnitudes of the probability amplitudes associated with physically possible paths of light rays vary at an inverse ratio with respect to their distances from their source particles, the probability for absorption here is inversely proportional to the square of that distance. This corresponds to the energy density (intensity) of the electromagnetic field. I will now deal with the multiple path case.

The multiple path case involves interference effects from among the contributions from the different physically possible paths. I wish to explain interference effects in terms of the claim that there is a superposition of rotational effects from among the previously-mentioned rotational waves when they meet a potential absorber. Since potential absorbers will impact each of the subspaces of the different rotational waves, there will thus be a superposition of their various effects. The probability for absorption then is given by the absolute square of the sum (the "kernel" as defined by Feynman (2, p. 26)) of the probability amplitudes associated with individual physically possible paths. Phase factors of these probability amplitudes account for constructive or destructive interference among the different paths.

Since I am using sine and cosine notation, kernels in my interpretation of Feynman's account will be comprised of two parts K_1 and K_2, corresponding to the summations of the respective probability amplitudes Φ_1 and Φ_2. K_1 and K_2 will thus correspond to the resultant rotational effects, taking all of the rotational waves together respectively of the waves for the E fields and the B fields. The sum of these two kernels will then determine the probability of absorption of the individual wave packets; e. g., the probability P for light to travel between two points a and b would be given by adding the squares of the two kernels:

$$P = \Psi\Psi^* = K_1^2 + K_2^2 = (\Sigma\Phi_1)^2 + (\Sigma\Phi_2)^2 \quad [7]$$

The summations are over all physically possible paths from a to b, and Φ_1 and Φ_2 are the probability amplitudes, as previously characterized, associated with wave packets for each physically possible path from a to b when these have been suitably normalized. The overall probability for absorption thus corresponds to the intensity at a given location of a superposition of the electromagnetic fields from the various source particles. It can be noted that Feynman (2, Ch. 4) has shown that the resulting differential equation here is the Schrodinger equation, although I will not summarize his derivation in this paper. It should also be emphasized again that it need not be the numerically same photon as that which is emitted from one source which is absorbed here, but that rather a discrete amount of energy is drawn from a 'pool' to which many different sources may contribute.(4)

In the case where light is not absorbed, I hold that two processes occur. First, elastic scattering will occur, where I hold that only a partial collapse of the wave packet takes place, with photons being literally divided into distinct portions in the process. These distinct partial photons will subsequently be propagated in different subspaces of spherical rotational waves, each possessing the same frequency as the original rotational wave and centered at the location of scattering. The second process involves light which is not scattered being 'pushed aside' (the Renninger (5) effect) creating a shadow in the given direction and increasing the density (and hence also the chances of absorption) from other locations. I will not derive the relative ratios (i. e., the cross sections) for scattering and the Renninger effect.

It can next be noted that a beamsplitter involves both the transmission and the reflection of light, and thus splits a light beam in two. According to standard quantum mechanics, a beamsplitter splits a probability wave but not a particle. Since I am identifying waves with particles though, the particle must also be split at the beamsplitter. It can be noted that beamsplitters are key optical components in classical interference experiments, where they are needed to separate beams before they are recombined, with a phase differential, at a detector. They are also key components with polarization entanglement experiments, which, after a brief digression on the absorption process, I will elaborate a bit on.

I hold that in the absorption process a discrete amount of energy ($E=h\nu$) is drawn from the distinct subspaces of each wave-particle (e. g., a partial photon) impacting on the absorbing particle. The relative ratios drawn from each subspace correspond to the partial photon densities at the location. The energy is drawn from along past trajectories until a node, involving a four-dimensional particle, is reached. The node plays the role of providing a four-dimensional 'link' between three-dimensional subspaces. The energy is then drawn from along other possible trajectories in subspaces centered on the node to other locations where the partial photon already has a 'presence.' The sense of 'presence' here is the same a s the sense in which the absorbed photon had a presence at its detector;

i. e., it had a potential to be absorbed there. I hold that this backwards then forward wave process must take place in the present; i. e., during the absorption time, and thus both waves must travel faster than c. The concept of a backwards wave here is analogous to the concept of an advanced wave developed by Klyshko (6), only under my conception of it, the wave does not go backwards in time and instead acts instantly in the present. I also believe that the backward then forward wave process just sketched is the key for explaining the correlations at a distance which occur in polarization entanglement experiments and thus I will now turn to a discussion of that subject.

In polarization entanglement experiments orthogonal signal and idler probability amplitudes are made to overlap at a detector. (7) It can be noted that the corresponding force field strengths are changed respectively at a $\cos\Theta$ and $\sin\Theta$ rate by a polarizer placed at an angle Θ to the original bases angles. Since the intensity (energy) of a field is given by the square of the force field strength, energy fields (from which photons, possessing a discrete packet of energy, are drawn) emerging from a polarizer are cut in accordance with Malus' law $I \propto \cos^2\Theta$. It should be emphasized here that, under my account, the original fields are not being cut in strength or filtered by the polarizer. Instead, since in effect I am defending an emission theory of light, I hold that new fields (driven by the old ones) are being created by the polarizer. A new basis of polarization is then given by the relevant Jones operator of the polarizer.

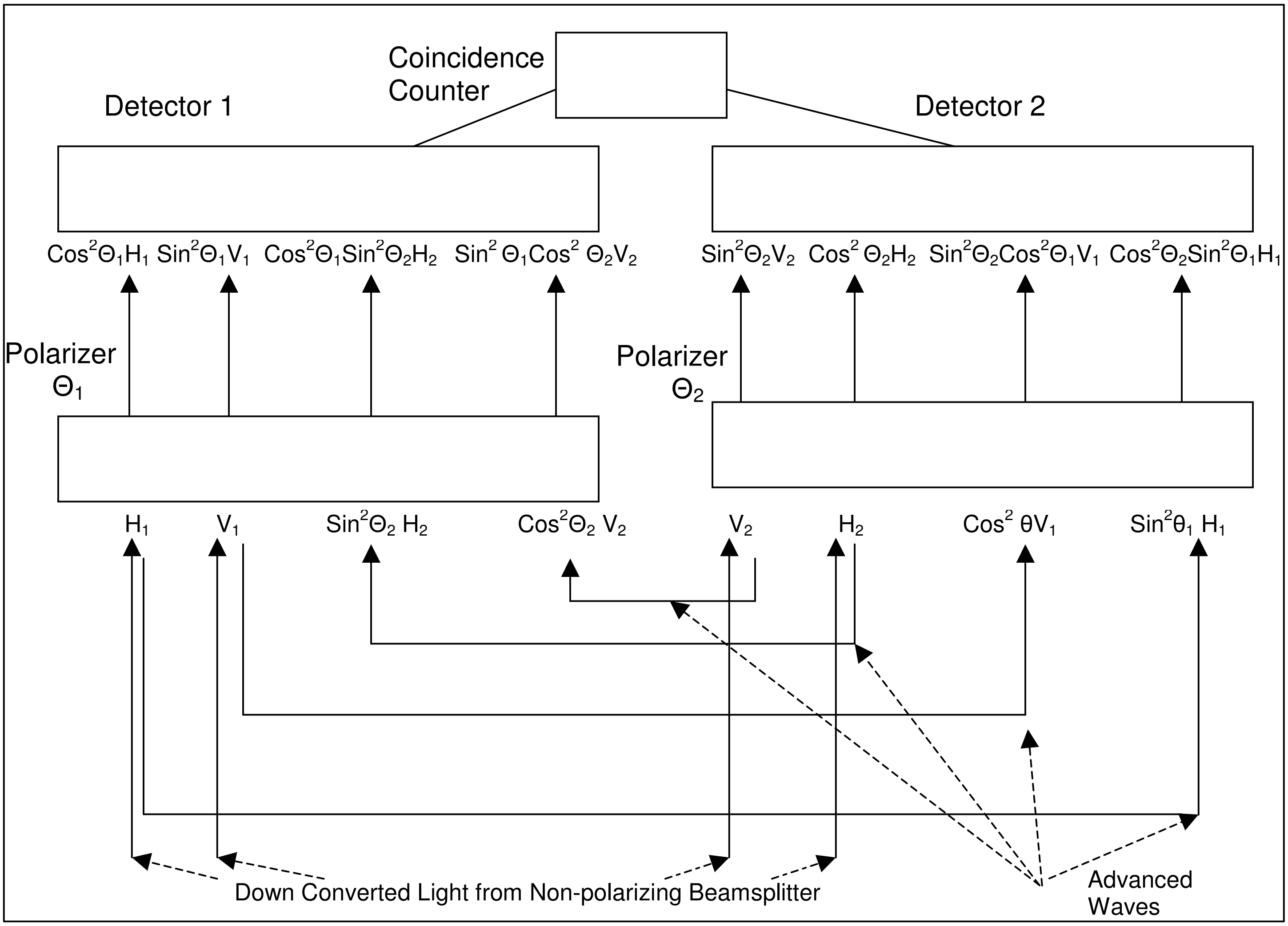

Diagram 1 Illustration of advanced waves from one detection system being cut by polarizers at the opposite detection system resulting in polarization entanglement.

It is now possible to identify the field components from which the energy is drawn from in both singles counting and coincidence counting in polarization entanglement experiments. First there are energy fields associated with the original signal and idler fields as they converge together at each individual detector. These energy fields are given respectively by $\sin^2\Theta_1 + \cos^2\Theta_1$ and $\sin^2\Theta_2 + \cos^2\Theta_2$ terms. Since $\sin^2\theta + \cos^2\theta = 1$ the total singles counts from combining the two energy fields will remain constant as a function of polarization angle. I will now turn to my discussion of the situation for coincidence counting, which is considerably more subtle

In my explanation of the non-local effects of polarization entanglement associated with coincidence counting I invoke advanced waves connecting the energy fields present at the two detection systems. These advanced waves are analogous to those proposed by Klyshko (6) except as I previously noted I do not hold that they go backwards in time. Also for the purposes of this paper I will leave it as an open question as to whether these waves are generated by the polarizers or by the detectors themselves. The four Bell states (8) can now be accounted for as follows.

For the $\Psi^{\pm}$ Bell states I hold that advanced waves from each of the energy fields at one detector are cut by the polarizers at the opposite detection system. This results in $\sin^2\Theta_1\cos^2\Theta_2\ H_2$ and $\cos^2\Theta_1\sin^2\Theta_2\ V_2$ energy fields being present at one detector and $\cos^2\Theta_2\sin^2\Theta_1\ H_1$ and $\sin^2\Theta_2\cos^2\Theta_1\ V_1$ energy fields being present at the other detector, as illustrated in diagram 1. The trigonometric identity $\sin\Theta_1\cos\Theta_2 = ½\ [\sin(\Theta_1 + \Theta_2) + \sin(\Theta_1 - \Theta_2)]$ can be invoked on each of these energy fields. When the $\sin^2(\Theta_1 + \Theta_2)$ and $\sin^2(\Theta_1 - \Theta_2)$ terms are expanded by the trigonometric identity $\sin(\Theta_1 \pm \Theta_2) = \sin\Theta_1\cos\Theta_2 \pm \sin\Theta_2\cos\Theta_1$ this results in the shared cross term (9) for all of the Bell states $2\sin\Theta_1\cos\Theta_2\sin\Theta_2\cos\Theta_1$. It can be noted that since $H_1 = H_2$, $V_1 = V_2$, and $\sin^2(\Theta_1 - \Theta_2) = \sin^2(\Theta_2 - \Theta_1)$ the sum and difference terms will be shared at each detector resulting in these same functions for coincidence counts. Similarly the $\Phi^{\pm}$ Bell states can also be explained by invoking the trigonometric identities $\sin\Theta_2\sin\Theta_1 = ½[\cos(\Theta_1 + \Theta_2) + \cos$

$(\Theta_1 - \Theta_2)]$ and $\cos\Theta_1\cos\Theta_2 = ½[\cos(\Theta_1 + \Theta_2) - \cos(\Theta_1 - \Theta_2)]$ for the case where advanced waves are cut by polarizers on a new set of basis beams changed in polarization by 45^0 by a quarter wave plate It can also be noted that in the case of each of the Bell states, due to the Young inequality $ab \leq a^p/p + b^q/q$ where $p = q = 2$, the cross term $\sin\Theta_1\cos\Theta_1\sin\Theta_2\cos\Theta_2$ is always equal to or less than the squared terms $\sin^2\Theta_1\cos^2\Theta_2$ and $\sin^2\Theta_2\cos^2\Theta_1$ or $\cos^2\Theta_1\cos^2\Theta_2$ and $\sin^2\Theta_2\sin^2\Theta_1$ and thus negative energy is never involved here.

By the preceding considerations, the energy of the ”partial photons” present at each detector can be jointly absorbed in either of two alternative ways $\sin^2(\Theta_1 \pm \Theta_2)$ or $\cos^2(\Theta_1 \pm \Theta_2)$ corresponding respectively to the $\Psi^\pm$ and $\Phi^\pm$ Bell states. The joint energy associated with these states can be measured by the difference between the polarization vectors of the two polarizers with coincidence counting. It should be emphasized that the photon absorption at each separate detector draws energy from the sets of energy fields jointly present at both detectors. This can be interpreted as the process of correlated two photon absorption from the combined energy fields present at the two detectors with correlated photon pairs from the fields being jointly absorbed by the process of correlated photon absorption. (10) It can be noted that it has been argued that this process can occur with two absorbers at a macroscopic distance from each other. (11)

My claim is thus that the energy fields associated with the polarization entanglement experiments are absorbed in tandem over the spatially extended region encompassing the two detectors. As Maudlin (12) emphasizes a special reference frame (e. g., that of the source particle) is required here. It can be noted that since the field properties depend on the polarization angles of both polarizers, they can only be measured by coincidence counts from both detectors. It can also be noted that Aspect's (13) experiments have shown that a common cause explanation of the correlations does not work. In his experiments the set of polarizers being sent to is changed in flight by fast acousto-optic switches after the photons have left their source. Since there is a space-like separation between the absorption events at the detectors the correlations cannot be explained by any subluminal communication between the detection events. It can be noted that at very low intensities of down-converted light (e. g., at the single photon level), there are anticorrelations, showing photon number squeezing, between detection events at two detectors after a beam has been separated by a beamsplitter. (14) Thus, as in the joint absorption case just discussed, the energy for the photon being absorbed is drawn from along past and forward trajectories in such a manner as to provide a link with the second detector. Depending on the nature of the experiment involved the key node, as previously defined, for creating the link may be in a beamsplitter or even in a down-conversion crystal. I should emphasize again that the foregoing account parallels the account in terms of advanced waves given by Klyshko (6) and also the transactional account of Cramer (15) only it does not involve backwards in time causation, which I find to be quite implausible.

It is noteworthy that this last claim may be empirically testable by blocking the backwards wave after a photon has been detected, possibly with a fast optical chopper. Here the detector must be located at a sufficiently great distance from the chopper so that at the moment of absorption, the chopper will be in a position to block the backward wave. This could be accomplished by feeding the light into optical fibers which are a few km in length (the record now for sending down converted light is over 100 km.) (16) so this should be technically feasible. Inasmuch as it is being held that the correlations are created by the backward then forward wave process just sketched, if the backward wave is blocked, this should destroy the correlated properties.

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