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MODEL BASIS STATES FOR PHOTONS AND "EMPTY WAVES"

Malcolm H. Mac Gregor

Lawrence Livermore National Laboratory
Livermore, California 94550
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From the perspective of physical realism (PR), a photon is a localized entity that carries energy and momentum, and which is surrounded by a wave packet (an *empty wave*) that is devoid of observable energy or momentum. In creating quantized PR basis states for a photon wave packet, three requirements must be met: *(1)* The basis states must each carry the frequency of the wave; *(2)* They must closely resemble the photon, so that e.g. they scatter in the same manner from an optical mirror; *(3)* They must have infinitesimal energy, linear momentum, and angular momentum. An essentially zero-energy "empty wave" quantum–a "zeron"–is defined which meets these requirements. It is created as an asymmetric single-particle (or single-antiparticle) excitation of the vacuum state, with the "particle" (or "antiparticle") and its associated "hole" (or "antihole") forming a rotational bound state. The photon is reproduced as a symmetric particle-antiparticle excitation of the vacuum state, with the "particle" and "antiparticle" also forming a rotational bound state. The relativistic transformation problem is discussed. A key point in this development is the deduction of the correct equation of motion for a "hole" state in an external electrostatic field.

Key words: photon model, photon wave quanta, empty waves.

1. INTRODUCTION

The case for physical realism (PR) has been clearly set forward in a book by Franco Selleri [1], who summarizes the situation as follows [2]:

> ... a detailed analysis of major experiments on the dual nature of quantal systems has revealed an almost unlimited scope for the fashioning of a *unitary* description of the phenomena involved, one in which every subatomic system (photon, electron, neutron, etc.) can

> be treated as an entity that exhibits not only localization, all the energy and momentum of the system being confined to a tiny region of space (as they are for a corpuscle), but also an extended phenomenon (the wave), devoid of any energy or momentum, traveling in close association with the "corpuscle". With the aid of this concept, we can explain:
> (1) the double-slit experiment;
> (2) the experiments of Jánossy and Naray;
> (3) the experiment of Clauser as well as that of Mandel and Dagenais;
> (4) the experiments of neutron interferometry;
> (5) the experiment of Pfleegor and Mandel;
> (6) the experiment of Blake and Scarl;
> (7) fluorescence in the vicinity of mirrors;
> (8) superfluorescence;
> (9) x-ray interferometry;
> (10) experiments on the Bohm-Aharanov effect;
> (11) experiments on electron interference.
>
> It is also interesting that this proposal for the description of micro-phenomena has consequences that can actually be studied concretely at an empirical level. ... Among the positive aspects of our proposal, one must cite the possible discovery of a new aspect of objective reality, the *empty wave*, and the obvious positive potential of this idea, whose full development requires a series of theoretical and experimental investigations.

As Selleri points out, the de Broglie *theory of the double solution* is in general agreement with this approach. Again quoting Selleri [3]:

> There remains, of course, the fundamental problem of the nature of the directly unobservable wave. On this point, a revolutionary thinker such as de Broglie prefers to be rather conservative and to assume that *almost* all energy-momentum is associated with the particle, but that a tiny fraction of it – so minute as to have escaped all means of observation thus far – is smeared out over the wave, as it were.

If we adopt the physical realism viewpoint, and then attempt to apply it to photon wave packets, we are faced with two tasks: *(a)* to develop a model for the "empty wave" that accompanies the photon; *(b)* to develop a model for the photon itself. In the present paper, we derive a representational mathematical model that can meet both of these needs. This model appears to be within the range of acceptable physical theories. The ultimate usefulness of such a model is to serve as a basis for *answering* questions. However, the more immediate usefulness of a specific model, which sometimes goes unrecognized, is to serve as a basis for *asking* questions. The model serves to delineate and highlight the questions that must be resolved for its implementation.

Perhaps the three major questions we face in dealing with the photon and its wave packet are the following: *(1)* Where do the *frequencies* of the photon and its wave packet come from? *(2)* How do we deal with the net *zero rest masses* of the photon and wave packet within the context of PR? *(3)* What can we say about special relativity for PR systems that are moving at the velocity of light? We can deal with the first two of these questions in a reasonably plausible manner, as we demonstrate below. However, at the present state of development, the third question remains quantitatively beyond our reach, although we can arrive at some qualitative conclusions.

In this paper we limit ourselves to the photon and photon wave packet, since these illustrate particle-wave dualism in a clear-cut manner. But the same general considerations must also apply to all particle-wave systems. We first develop a model for the "empty waves" of the photon wave packet. Then we extend this model to include the photon, whose properties are quite well constrained by the available experimental data. The vacuum-state excitation mechanism that is postulated here seems more compelling when both the photon and empty-wave models are studied together than when either is considered separately, since essentially the same basic formalism ties these two different kinds of physical systems together.

2. THE QUESTION OF PARTICLE AND WAVE FREQUENCIES

In studying the properties of interacting wave functions, we usually deal with wavelengths λ rather than frequencies ν, since the wavelengths are easily used to deduce the phase relationships, and hence the interference effects, of the waves. However, from a basic theoretical standpoint, frequencies ν and velocities v are probably more fundamental, with $\lambda = v / \nu$ appearing as a derived quantity. In de Broglie's pioneering thesis on matter waves, he dealt mainly with the question of frequencies, and he was well along in the thesis before he wrote down the famous de Broglie wave equation, $\lambda = h / p$. From the PR viewpoint, the frequency of a matter wave is a property of the wave itself, and, in the case of divided wave packets, the frequency exists independently of whether or not a particle is present in that portion of the wave packet. De Broglie's great discovery was the realization that the *frequency* ν of the matter wave is directly proportional to the *mass m* of the particle that produced it:

$$h\nu = mc^2. \tag{1}$$

In the present model, we cannot give an explanation as to why this equation is valid, but we can demonstrate empirically how a *mass* term for the particle is related to a *mass* term in the wave, which in turn is related to the *frequency* of the wave.

We might suppose that the frequency in a particle wave packet is related to a frequency within the particle itself. And, for the photon, this seems to be the case. However, in the case of massive particles, this assumption quickly runs into insurmountable difficulties. If we construct the simplest relativistically spinning sphere (RSS) model that we can devise for the electron, it turns out that the rotational frequency of the sphere does in fact match the wave frequency [4]. But if we modify this RSS model to take account of quantum mechanical considerations, the frequency relationship is lost [5]. We can extend this RSS model to apply also to constituent quarks [6]. If we then construct nucleons from three quarks and mesons from quark-antiquark pairs, it quickly becomes apparent that the frequencies of the spinning quarks bear no relationship to the corresponding wave frequencies that we deduce from Eq. (1). Furthermore, complex systems such as helium atoms also generate waves which accurately obey Eq. (1), and yet the helium atom itself does not contain the frequency of the wave. Thus wave *frequencies* come from the associated particle *masses*, and not, except in the case of the massless photons, from frequencies within the particles.

If we accept the above argument as being correct, we are still faced with the problem as to what the wave frequency *is*. From the PR standpoint, a frequency corresponds to a rotation or a vibration. Thus a particle wave must contain elements that are rotating or vibrating. In the case of photons, we know that a single photon is circularly polarized, so that the photon is rotating and not vibrating (as would be the case for plane polarization). This singles out a rotation as the frequency generator in a photon, and hence also in its associated electromagnetic wave. This conclusion is reinforced when we study the vacuum excitation process that leads to the formation of wave quanta, which we do in the next section. This vacuum excitation process is pictured here as occurring via the creation of particle-hole pairs, and these pairs can be shown to have stable or metastable configurations only when they are rotating.

3. PARTICLE-HOLE EXCITATIONS OF THE VACUUM STATE

We know that whenever sufficient energy is available, a particle-antiparticle pair can be produced. We also know that even when insufficient energy is available, virtual particles are momentarily produced. These virtual particles give rise to the vacuum polarization effects of quantum electrodynamics. They also give rise to a directly observable macroscopic effect: the Casimir force that occurs between two closely spaced uncharged condenser plates. The production of these virtual particles seemingly violates the conservation of energy, with the duration of the violation limited by the Heisenberg uncertainty principle, $\Delta E \cdot \Delta T \equiv \hbar$. However, there is a way we can picture the creation of these particles that does not violate energy conservation. Instead of forming a virtual particle-antiparticle pair, we can form a virtual particle-hole (*P-H*) pair. In this process, a "particle" is lifted out of the vacuum state, thus leaving behind a "hole" in the vacuum. The net total energy of the *P-H* pair is much smaller than the energy contained in the particle *P*. Thus the hole *H* appears as a "negative energy" in the overall energy equation. However, *H* does not

play the role of a "negative-mass particle," at least in the sense that these particles are customarily discussed in the literature [7]. In order to clarify this assertion, and to make the discussion specific, we invoke the following model for the excitations of the vacuum state:
The vacuum state is pictured as containing two distributed mass and charge lattices:

(L1) a particle-mass lattice studded with negative electric charges $-e$;
(L2) an antiparticle-mass lattice studded with positive charges $+e$.

Correspondingly, there are two basic lowest-order vacuum excitation processes:

(E1) a negatively charged particle is lifted out of the particle lattice *L1*, leaving behind a vacant hole that appears to be positively charged;
(E2) a positively charged antiparticle is lifted out of the antiparticle lattice *L2*, leaving a vacant antihole that appears to be negatively charged.

We further assume that once a particle-hole pair has been created, both the particle and hole can move freely through the vacuum state; that is, they each take on the role of a dynamical variable. The same assumption applies to an antiparticle-antihole pair. This brings us to a crucial point in the development of these ideas. The hole and antihole states, under the action of an external electrostatic field, do *not* obey the equations of motion of a "negative mass state," as we demonstrate below.

Negative masses have been extensively discussed in the literature. The possibility of negative-mass states is permitted by the equations of special relativity [7], and the motions of negative-mass states are defined by these equations. However, such states have never been observed experimentally. Furthermore, Hoffmann [8] has pointed out that whereas the equations of *special relativity* are symmetric with respect to positive and negative masses, the equations of *general relativity* are not. He cites three examples: *(a)* the Schwarzschild general-relativistic line element contains the well-known Schwarzschild singularity for $+m$ solutions, but not for $-m$ solutions; *(b)* the loci of spaces t = constant can be constructed only for a $+m$ manifold; *(c)* gravitational waves always carry positive energy. Thus general relativity applies only to positive-mass spatial manifolds, such as we envisage in the lattices *L1* and *L2* described above.

For our present purposes, the crucial distinction between "negative masses" and "holes in positive-mass manifolds" lies in their different equations of motion, which is a result that seems to be original with the present author. Using Newtonian mechanics as the basis for discussion, we can obtain the equations of motion for negative masses by simply reversing the sign of m in these equations [7]. Thus we have

$$\mathbf{P} = +m\mathbf{v}, \quad d\mathbf{P}/dt = \mathbf{F} = +m\mathbf{a}, \quad \text{positive-mass state}, \tag{2}$$

$$\mathbf{P} = -m\mathbf{v}, \quad d\mathbf{P}/dt = \mathbf{F} = -m\mathbf{a}, \quad \text{negative-mass state}. \tag{3}$$

If a force is applied to a negative-mass state, it acts perversely by moving in the direction opposite to the force. This result holds for all external mechanical and electromagnetic forces. Discussing the electromagnetic case, Terletskii commented as follows [9]: "Thus, in an external electric field, identically charged particles of positive and negative mass will be accelerated in opposite directions." However, as we emphasize here, this result does *not* apply to hole (or antihole) states. *A hole state is not acted on directly by external forces.* The hole is merely a vacancy in the spatial lattice: there is nothing there to act on. If an external force is applied, it acts on the *neighbors* of the hole state, who have *different degrees of freedom* than they would have if the hole were not present (this is the operational definition of a "hole" in the lattice). Viewed in this context, the application of external *mechanical* or *electrostatic* forces to a hole state leads to different results in the two cases. Suppose an external mechanical force is applied from the left. It forces the left-hand neighbor of the hole into the hole, thus moving the hole to the *left*, in the direction opposite to that of the applied force. The momentum change is to the right, but the position change of the hole is to the left. The equations of motion are

$$\mathbf{P} = -m\mathbf{v}, \quad d\mathbf{P}/dt = \mathbf{F}_{mech} = -m\mathbf{a}, \quad \text{hole or antihole state}, \quad (4)$$

where m is the magnitude of the mass (or, more accurately, the magnitude of the total energy) that has been removed during the creation of the hole state, and where $\mathbf{v}$ and $\mathbf{a}$ refer to the motion of the hole. Thus, with respect to external *mechanical* forces, a hole state acts just like a negative mass. But now consider the application of an external *electrostatic* force. Electrostatically, to an external test charge, the hole appears to be a positively charged electrical object. Let us apply an external electrostatic field that would move a *positive* charge to the *right*. This external field does *not* act directly on the hole, since nothing is there. It acts instead on the neighbors of the hole. Specifically, it acts on the right-hand *negatively charged* neighbor of the hole and forces it (charge and mass) to the *left* and into the hole, thus moving the hole to the *right*, in the direction of the applied force. Hence a hole state moves (positionally) under the action of an external electrostatic force in the same manner that a positive-mass state would move. We have

$$\mathbf{P} = -m\mathbf{v}, \quad -d\mathbf{P}/dt = \mathbf{F}_{elec} = +m\mathbf{a}, \quad \text{hole or antihole state}, \quad (5)$$

where m again is the magnitude of the total energy that has been removed from the hole or antihole state. This may seem to be a simple result, but it is a result that has apparently not been recognized until now, and it is crucial from the standpoint of the behavior of spatial mass-and-charge vacuum state excitations.

The difference between Eq. (3) for a negative mass and Eq. (5) for a hole or antihole is important for two reasons: *(a)* it has a dramatic effect on possible vacuum state excitation processes (vacuum fluctuations); *(b)* it has an equally dramatic effect on "empty wave" rotational dynamics. We discuss *(a)* here, and we discuss *(b)* in the next section. Consider the spatial excitation of a hypothetical *positive-mass plus negative-mass* pair, where these quanta carry opposite electrical charges. After these quanta have been excited and separated, the electrostatic attraction between their charges tends to draw them together again. But this doesn't happen. The positive-mass quantum moves in the direction of the force, in accordance with Eq. (2). However, the negative-mass quantum moves in the direction opposite to that of the force, in accordance with Eq. (3). Thus this excited pair maintains its separation: *there is no mechanism for de-excitation!* By way of contrast, consider the spatial excitation of a *positive-mass plus hole* pair. After excitation, the electrostatic attraction draws the positive-mass quantum towards the hole state (Eq. 2), and it also draws the hole state towards the positive-mass quantum (Eq. 5). Thus a *positive-mass plus hole* pair, once excited, quickly de-excites. This furnishes a plausible mechanism for continual disturbances of the vacuum state. We know from phenomena such as the Casimir force and vacuum polarization that charge fluctuations of the spatial manifold lead to observable effects. *Positive-mass plus hole* excitations logically lead to this type of spatial behavior, whereas *positive-mass plus negative-mass* excitations do not.

An important question arises here: are there any stable or metastable configurations for particle plus hole (P–H) and antiparticle plus antihole ($\overline{P}-\overline{H}$) vacuum state excitations? Significantly, there is one way that we can form a stable P–H or $\overline{P}-\overline{H}$ excitation: *we can put it into rotation at an appropriate angular velocity.* If we do this, then the centrifugal force prevents the particle (antiparticle) quantum from moving towards the attractive hole (antihole) state, and, as we will see, the Coriolis force and centrifugal force combine to prevent the hole (antihole) state from moving towards the attractive particle (antiparticle) quantum. It turns out that this same rotational mode, in a somewhat different excitation configuration, mathematically reproduces the properties of the photon. Before we consider the photon, we will construct a model for the quanta of the empty wave packet that surrounds and accompanies the photon.

4. THE QUANTA OF THE "EMPTY WAVE" IN THE PHOTON WAVE PACKET

From the standpoint of physical realism, a moving particle generates a wave packet that accompanies and to some extent "steers" the particle. The excitation of this wave packet occurs for all types of particles. The wave packet carries no detectable amount of energy, momentum, or angular momentum, and when the particle is detected (stopped), the wave packet simply disappears. The *frequency* of the waves is dictated by the *mass* of the moving particle, in accordance with Eq. (1). The particle mass thus serves as the "coupling constant" between the particle and the perturbation of the vacuum state. The "particle-wave" is apparently created directly out of the vacuum state, and it must in some sense represent the simplest type of excitation of the vacuum state. The excitations *E1* and *E2* described above, in which a particle or antiparticle is displaced from its position in the *L1* particle lattice or *L2* antiparticle lattice, represent lowest-order vacuum state processes, and therefore appear as viable candidates for particle-wave quanta. Since these wave quanta must have infinitesimally small energies, we will refer to them as "zerons," so as to clearly distinguish them from the finite-energy photons.

There are a number of properties of photon wave packets which suggest that they have a quantized (cellular) composition: *(1)* the wave packet of a freely-moving photon does not indefinitely spread out at the boundaries; *(2)* a wave packet can be fragmented and "sieved" through a half-silvered mirror, and it accurately reforms on the other side; *(3)* the Huygen's spherical wave front, which occurs after a wave packet passes through a small opening or past a sharp boundary, indicates that there is a break-up of the planar wave packet, with the individual "cells" scattering outward at the velocity c, and with each cell carrying the frequency of the wave. The picture of the photon wave packet as consisting of a cloud of *zerons* leads to this kind of a cellular composition for the wave packet. A group of in-phase zerons, as viewed in the rest frame of the photon, can be shown to bind together electrostatically in a nearest-neighbor manner to form the wave packet.

We now derive the equations of motion for a zeron particle-hole rotational bound state. First, consider a particle P that is displaced from its position in the spatial lattice *L1*. The particle carries off a negative electric charge $-e$, which we will equate for simplicity with the unit charge on the electron. We assume that the hole H which is left behind keeps its spatial integrity. Since a charge has been removed from *L1*, the hole H appears to be positively-charged, although it in fact has no charge. Work is required to separate the charged particle P^- from its position in the lattice, and this work is equal to the electrostatic potential between the negative charge on P and the (apparently positively charged) "gap" in the negative charge field of *L1* that is created by the presence of the hole H^+. We can write the potential energy of the $P^- - H^+$ pair in the form

$$\Delta \equiv e^2/2r, \tag{6}$$

where $2r$ is the separation distance between P and H. Once this P–H disturbance is created, the electrostatic attraction serves to draw P^- and H^+ together, in accordance with Eqs. (2) and (5), and thus de-excite the pair. However, if the pair is set into rotation, then the rotational motion serves to keep the pair apart, as we now demonstrate.

Let us consider first the dynamical equations for the particle member P^- of the rotating $P^- - H^+$ pair. The mass of this quantum is m, and it carries an electric charge $-e$. In order to have a stable rotating orbit, the outward centrifugal force must be counterbalanced by the inward electrostatic attraction. Thus we must have

$$m\omega^2 r \; = \; e^2/4r^2, \tag{7}$$

where $2r$ is the charge separation distance and ω is the angular velocity. We now attribute a quantized orbital angular momentum of $\hbar/2$ to this rotating mass (which forms half of the rotating pair). This gives

$$\hbar/2 \; = \; mr^2\omega\,. \tag{8}$$

Eliminating the mass m from Eqs. (7) and (8), we obtain the energy equation

$$\hbar\omega \; = \; e^2/2r \; \equiv \; \Delta\,, \tag{9}$$

where Δ is the electrostatic potential energy defined in Eq. (6). Since $\hbar\omega$ is the energy quantum defined by Planck for electromagnetic radiation of frequency ω, we will refer to Δ as the *Planck energy* of this rotating system.

Using units in which c = 1, we obtain the following value for the rotating mass m in terms of the Planck energy Δ:

$$m/\Delta \; = \; 2/\alpha^2, \tag{10}$$

where $\alpha \equiv e^2/\hbar c$ in cgs units is the fine structure constant. Since $\alpha \cong 1/137$, the dimensionless factor $2/\alpha^2$ is numerically equal to 37,558. Thus the mass m is an enormous mass as compared to the electrostatic energy of the $P - H$ pair. (It is interesting to note that $2/\alpha^2$ is also the ratio of the electron mass to its binding energy in a hydrogen atom [10].)

The instantaneous linear velocity of the rotating quanta P and H in the photon frame of reference is

$$\mathrm{v} \; = \; \omega r \; = \; e^2/2\hbar \; = \; 1.1\times 10^8 \;\; \mathrm{cm/sec} \tag{11}$$

for all values of the $P - H$ rotational frequency. (This velocity is equal to the velocity of an electron or positron in the positronium ground state [10].)

One important point to note about Eqs. (7) and (8), which are the equations that constrain the $P - H$ pair, is that they constitute two equations in three unknowns: m, ω, r. Hence these equations are underconstrained, which has the practical effect that we must use an assumed value for the frequency ω as the third constraint. Thus we can construct a stable rotating $P-H$ pair for any frequency ω, which is in line with the experimental fact that photons occur at all energies, and hence with all frequencies, and the frequency of the zeron wave quantum must match that of the accompanying photon.

Now consider the dynamical equations for the H^+ hole state of the rotating P–H pair. As Eq. (5) shows, the *acceleration* **a** of the position of the hole H is the same under an applied electrostatic force as that of a corresponding particle state P, but the *linear momentum* **P** is reversed. Let us first view the rotation of the P–H pair in a non-rotating coordinate system, as shown in Figure 1. With the counterclockwise rotation shown in Fig. 1, the particle quantum P at the top has its momentum vector **P** directed to the left. The momentum change d**P** due to the electrostatic attraction is directed inward, so the linear momentum vector is rotated counterclockwise, and P travels along the circular path indicated in the drawing. The hole quantum H at the bottom has its linear momentum vector **P** directed to the left (opposite to its linear velocity **v**). The momentum change d**P** due to the electrostatic attraction is directed outward

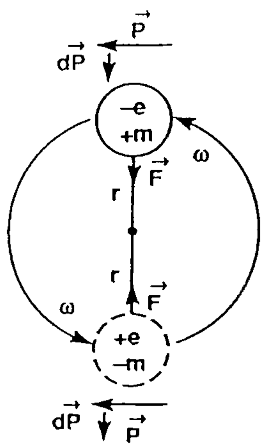

Fig. 1. A model for the zeron, the "empty wave" quantum, as viewed in a *non-rotating* frame of reference which is co-moving with the zeron. The rotating particle-hole pair $P^- - H^+$ represents an *E1* excitation of the *L1* spatial lattice. A similar figure applies to *E2* excitations. The "particle" state P^- at the top moves in accordance with the standard Newtonian equations (Eq. 2). The "hole" state H^+ at the bottom moves in accordance with Eq. (5). The vector relationships are such that each member of the rotating pair follows the same circular orbit, with the electrostatic attraction holding the pair together. The angular momentum of this rotating system is formally equal to zero, and its total energy (Eq. 15) is infinitesimal.

(opposite to the acceleration a), so that the linear momentum vector and the velocity vector (which is in the opposite direction) are both rotated counterclockwise, and H travels along the same circular path as P.

We now view the P–H pair in a frame of reference that is rotating at the angular frequency ω, as shown in Figure 2. In this frame, the positions of P and H are stationary. The inward electrostatic force on the quantum P causes an inward mass acceleration $d\mathbf{P}/dt$ that is counterbalanced by the outward centrifugal force $m\omega^2 r$. The case for the hole state H is more complex. The inward electrostatic force on the quantum H causes an inward acceleration of its position vector, which corresponds to an outward acceleration of mass: $d\mathbf{P}/dt$ is outward, as shown in Fig. 2. In addition to this electrostatically-induced motion, there are two rotational forces operating. The motion of the hole to (say) the *right* actually corresponds to a streaming of mass to the *left*. The centrifugal force that corresponds to this mass motion is

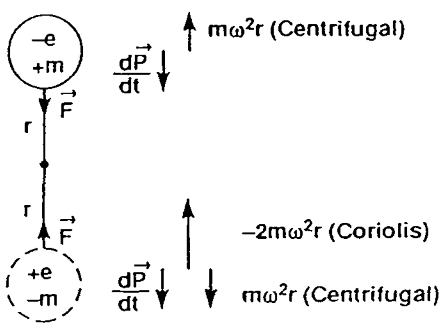

Fig. 2. The P–H zeron model of Figure 1 as viewed in a *rotating* frame of reference which is co-moving with the zeron. The positions of P and H in this coordinate frame are stationary, but the masses that constitute the boundary of the hole state H are constantly changing. In the case of the "particle" state P^- at the top, the inward electrostatic attraction causes an inward momentum change $d\mathbf{P}/dt$, which is balanced by the outward centrifugal force. In the case of the "hole" state H^+ at the bottom, the inward electrostatic attraction causes an *outward* momentum change. This is balanced by two rotational forces that arise from the mass streaming in the direction opposite to the motion of the hole: *(1)* a centrifugal force (Eq. 12) that is directed outward; *(2)* a Coriolis force (Eq. 13) that is directed inward. Thus the force equations balance out for both the particle state P and the hole state H.

$$F_{\mathrm{CENT}} = -m\,\vec{\omega}\times(\vec{\omega}\times\mathbf{r})\,. \tag{12}$$

Since this equation is independent of the sign of $\vec{\omega}$, the centrifugal force is always directed outward, regardless of the direction of the streaming motion. Hence the hole state H experiences the same outward centrifugal force as does the particle state P, as indicated in Fig. 2. Since the position of the hole in Fig. 2 is stationary, it might seem at first glance that there is no Coriolis force. However, the masses that form the boundaries of the hole are not stationary. There is a streaming of mass in the direction opposite to that of the rotating coordinate system. Thus there is a Coriolis force [11]

$$F_{\mathrm{COR}} = -2m\,\vec{\omega}\times\mathbf{v} \tag{13}$$

which is directed inward, and which has a magnitude of $2m\omega^2 r$. The two rotational forces combine to produce a net *inward* force of $m\,\omega^2 r$, which offsets the outward $d\mathbf{P}/dt$ force that corresponds to the electrostatic acceleration. Hence both the P and H components of this rotating system have balanced compensating forces, and both follow the same circular trajectory.

If we try to reproduce these results using a *positive-mass plus negative-mass* pair, the negative-mass quantum keeps running off in the wrong direction, and no stable rotation is possible, as can be verified by direct calculations. Thus Eq. (5) is an essential part of the present formalism.

The rotating $P-H$ pair shown in Figs. 1 and 2 constitutes a model for the zeron, the wave quantum of the photon wave packet. We know empirically that the total energy ε of a zeron must be infinitesimally small [12]. The total energy of the zeron in this frame of reference is made up of six components: *(1)* the rest mass energy of the particle state P; *(2)* the rotational kinetic energy of the particle state P; *(3)* the "rest mass energy" of the hole state H; *(4)* the "kinetic energy" of the hole state H; *(5)* the electrostatic energy Δ of the $P-H$ pair; *(6)* the infinitesimal energy ε that comes from the moving particle in the zeron excitation process [12]. The sum of the first five terms must be identically zero. Relativistically, we can combine components *(1)* and *(2)* into a single equation, which we write in a Newtonian expansion as

$$mc^2 \cong m_0c^2 + 1/2\,m_0\mathrm{v}^2\,, \tag{14}$$

where v is the linear velocity given in Eq. (11). Hence, by using the relativistic mass m for P rather than the non-relativistic mass m_0, we include both the rest-mass energy and kinetic energy in a single term. We assume that Eq. (14) also applies to the magnitude of the mass in H. Thus the energy equation for the zeron can be written as

$$-m_H + m_P + \Delta \;\equiv\; \varepsilon \quad , \tag{15}$$

where the mass m is the absolute value of the relativistic mass of the state. Since $\varepsilon \ll \Delta$, we have

$$m_H - m_P \;\cong\; \Delta \quad . \tag{16}$$

Hence the absolute magnitude of the hole state mass m_H is larger than the removed particle mass m_P by an amount which is equal to the Planck energy Δ required to remove the negative charge on P from its normal place in the lattice $L1$. We have thus exploited the freedom to choose different magnitudes for m_H and m_P, and have used this freedom to create a "zeron" state with an infinitesimal energy ε. "Antizeron" states are created in the same manner out of antiparticle-antihole excitations of the lattice $L2$.

The angular momentum of a revolving mass is given by the product $\mathbf{r} \times \mathbf{P}$, where $\mathbf{r}$ is the radius vector and $\mathbf{P}$ is the instantaneous linear momentum vector. We can see from Fig. 1 that the momentum $\mathbf{P}$ for the particle P is directed along the direction of rotation, but the momentum $\mathbf{P}$ for the hole H is directed in the opposite direction. Thus the angular momenta for these two states are $+\hbar/2$ and $-\hbar/2$, respectively (where we disregard the small difference in the masses). Hence the total angular momentum of the revolving $P-H$ pair is essentially zero, so that the zeron has both an infinitesimal energy ε and a vanishingly small angular momentum. When the revolving zeron is set into motion, the linear momentum in the forward direction is also vanishingly small. This model for the zeron therefore satisfies the three conditions that we set forth in the abstract to this paper.

The fact that the revolving masses m_P and m_H in Figs. 1 and 2 are not quite equal has a small effect on the rotational dynamics. To evaluate the magnitude of this effect, we define a zeron mass perturbation parameter δ:

$$\delta \;\equiv\; \Delta / m \;=\; 1/37{,}558 \quad . \tag{17}$$

If we keep the separation radius $2r$ fixed under the mass perturbation, the angular frequency ω is also fixed (Eq. 9). The centrifugal force equation (Eq. 7) remains balanced to first order in δ if the center of rotation is shifted in the direction of the larger (absolute) mass by 1/2 δ, or roughly one part in 10^5. The angular momentum equation (Eq. 8) remains unchanged to first order in δ if the center of rotation is shifted by 1/4 δ. Thus the small $m_H - m_P$ mass difference that we invoke in order to obtain a "zero-mass" quantum has only a minor effect on the zeron dynamics.

The existence of "zero-energy" empty electromagnetic waves can be used to solve another difficulty. The Casimir effect, in which a force is measured to exist between two closely spaced but uncharged metal plates, can be explained as a consequence of the charge fluctuations of the vacuum state [13]. However, the energy that is calculated to be associated with these fluctuations turns out to be infinite. If we associate these fluctuations mainly with zerons rather than photons, then an avenue is opened up for resolving this problem.

The introduction of a "hole" in the vacuum state as a dynamical variable may seem to be a radical assumption [14], but it is phenomenologically mandated by the properties of zeron wave quanta, and even more so by the known properties of photons, which we now discuss. Without this extension of our theoretical framework, we remain at a conceptual impasse [15].

5. A MODEL FOR THE PHOTON

The photon is the quantum of the electromagnetic field. Perhaps its most salient features are the following: *(1)* it has zero net charge, but serves as the carrier for the transverse electromagnetic field; *(2)* it has zero rest mass, but carries a spin angular momentum of $\hbar$. We can conclude from *(1)* that if the photon has electric charges, these must be in the form of an *electric dipole* (or possibly several dipoles). Furthermore, since single photons are circularly polarized with respect to the line of motion, this electric dipole must be rotating in the plane perpendicular to the line of motion. We can conclude from *(2)* that if the photon carries masses, these must be in the form of particle-hole and antiparticle-antihole *mass dipole* pairs. Furthermore, since the angular momentum of the photon is directed parallel or antiparallel to the line of motion of the photon, these pairs must be rotating in the same plane as the electric dipole. The obvious conjunction of these ideas is to form a model photon from rotating charge-and-mass pairs. The notion of the photon as a traveling electric dipole was studied by Bateman [16], who concluded that this concept is in agreement with Maxwell's equations [17]. It was further studied by Bonnor, who added masses to the charges, and who studied the problem within the context of both special [18] and general [19] relativity. Bonnor demonstrated that the electromagnetic energy content of an electric dipole traveling at the velocity of light is finite. Discussions of electric charges moving close to the velocity of light have also been discussed, for example, by Jackson [20] and by French [21].

In this section, we first list the properties of the photon. Then we describe a photon model. Finally, we mention some theoretical studies on traveling electric charges and masses that have a bearing on the viability of such a model.

5.a. The Properties of the Photon

The main properties of a free space photon are the following:

A. Energy: $E = \hbar\omega = hf$.
B. Linear momentum: $P = E / c = hf / c$.
C. Spin angular momentum: $J = \hbar$.
D. Velocity: $v = c$.
E. Wavelength: $\lambda = c / f$.
F. Rest mass: zero (mass $< 3 \times 10^{-33}$ MeV)[22].
G. Net electrical charge: zero (charge $< 2 \times 10^{-32}$ e)[22].
H. Electromagnetic field components: transverse only.
I. Spin angular momentum components: $\pm\hbar$ along the line of motion.
J. Parity: negative.
K. Particle-antiparticle symmetry: balanced.

5.b. The Photon Model

Consider a photon interferometer experiment from the viewpoint of physical realism. If this experiment is carried out at low intensity, a single photon and its accompanying wave packet enter the apparatus and travel through it. When a half-silvered mirror is encountered, the photon and a portion of the wave packet go in one direction (either reflected or transmitted), and the remainder of the wave packet goes in the other direction (either transmitted or reflected). Both components obey the same laws of optics while traveling on these two different paths, and they then combine coherently at the end of the apparatus. Thus the quanta that make up the wave packet–the empty wave–must have properties which are essentially identical to those of the photon itself. Hence if we attempt to reproduce the photon within the context of physical realism, we must use the same model (with suitable modifications) that we used above for the zeron quanta of the empty wave. In particular, the photon must have precisely the same *frequency* as the zerons. If we picture the zeron as a rotating particle-hole pair, as we have done here, we are virtually forced into picturing the photon as being similarly formed. In order to rotate at the same frequency, these dynamical structures must have comparable masses and radii.

The angular momentum of the photon is a real physical quantity: a beam of circularly polarized photons striking a quarter-wave plate produces a macroscopically observable rotation [23]. From the standpoint of physical realism, this angular momentum is carried by the photon itself, and not by the associated wave packet [24]. Thus the photon model, in contrast to the zeron model described above, must reproduce the photon angular momentum of $\hbar$. If we use the same basic equations for the photon as we did for the zeron, this implies that each member of the rotating pair must contribute $\hbar / 2$ to the angular momentum [25]. Hence they must each have an instantaneous linear momentum **P** that is directed parallel to the velocity vector. That is, they must each represent a "particle" state, and not a "hole" state. Furthermore, since the photon, from its particle-antiparticle production modes, is known to have particle-antiparticle symmetry, the rotating pair in the model photon logically consists of a "particle" and an "antiparticle."

In constructing a quantum for the PR "empty wave," we pictured this quantum, the "zeron," as being produced either by *(1)* an *E1* excitation ($P^- - H^+$) of the *L1* particle-mass vacuum-state lattice, or *(2)* an *E2* excitation ($\overline{P}^+ - \overline{H}^-$) of the *L2* antiparticle-mass lattice. Guided by the above discussion, we construct the photon as a simultaneous *E1* plus *E2* excitation of the *L1* and *L2* lattices. From angular momentum considerations, the excited P^- and $\overline{P}^+$ "particles" must be rotating, and the corresponding H^+ and $\overline{H}^-$ "holes" must be rotationless. Hence it is clear phenomenologically that when the photon *E1* - *E2* excitation pair is produced, the H^+ and $\overline{H}^-$ hole states are drawn together and coalesce, and the P^- and $\overline{P}^+$ particle states revolve around this common center, held together by their electrostatic attraction. This configuration is displayed in Fig. 3.

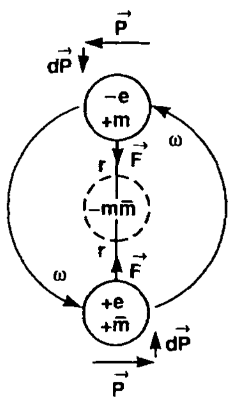

Fig. 3. A model for the photon, as viewed in a *non-rotating* frame of reference which is co-moving with the photon. This configuration represents a simultaneous *E1* plus *E2* excitation of the *L1* and *L2* spatial lattices. The rotating particle-antiparticle pair $P^- - \overline{P}^+$ reproduces the salient characteristics of the photon. The coalesced hole-antihole pair $H^+ - \overline{H}^-$ at the center does not contribute electromagnetically, but it contributes to the overall mass balance. The P^- and $\overline{P}^+$ "particles" are held together electrostatically, and their combined angular momentum is $\hbar$. The laboratory frame electromagnetic fields for this model are shown in Fig. 4.

The dynamical motion of the rotating $P-\overline{P}$ pair shown in Fig. 3 is given by Eqs. (6) - (11), the same equations we used for the zeron. Thus the photon model of Fig. 3 and the zeron model of Fig. 1 exhibit the same rotational characteristics, as they must in order to form a synchronous coupling. If we use Eq. 9 to define the total energy of the model photon as being equal to $\hbar\omega$ in this frame of reference, then the total (negative) energy of each hole state must be equal to the relativistic mass (rest mass plus rotational kinetic energy) of the corresponding particle state, so that Eqs. (15) and (16) now become

$$-m_H - m_{\overline{H}} + m_P + m_{\overline{P}} + \Delta \;=\; \hbar\,\omega \tag{15'}$$

and

$$m_H - m_P \;=\; m_{\overline{H}} - m_{\overline{P}} \;=\; 0 \;, \tag{16'}$$

where m is the absolute value of the relativistic mass of Eq. (14). With this assumption, we have a model photon that reproduces the standard properties of single photons. In this frame of reference, which is moving with the photon, the total energy $\hbar\omega$ is equal to the Planck electrostatic energy Δ, and the angular momentum is $\hbar$. In the laboratory frame of reference, the electromagnetic field of the photon is circularly polarized. Also, the inertial properties of the particles and holes in the photon cancel out in the forward direction, so that the forward linear momentum in the laboratory frame arises from just the electromagnetic energy term. The electromagnetic energy of the moving laboratory-frame photon contains both electric and magnetic components, as we discuss at the end of the next section. The magnetic component arises mainly from the forward motion of the electric charges on P and $\overline{P}$. The electromagnetic fields of this forward-moving photon are shown in Fig. 4. As discussed in the next section, these fields are in agreement with Maxwell's equations. The difficult problem of dealing with finite masses within the context of special relativity is considered in Sec. 6.

Since we use Eqs. (6) - (11) to define the dynamics of both the single *E1* or *E2* excitation of a zeron (Fig. 1), and the double *E1 plus E2* excitation of a photon (Fig. 3), we are implicitly assuming that the coalesced hole states in the photon excitation do not contribute to its electromagnetic field. However, this then opens up the question as to which forces are operating to confine the hole states inside the photon. It seems plausible that such forces exist, but we do not have an electromagnetic answer to this question. The photon model that we have invoked here provides answers to some questions about the photon, but it creates other questions. As we mentioned at the beginning of this paper, one of the useful aspects of such a model is to raise as well as answer questions. We would of course like to have answers to all of these questions, but progress can in some cases be made only after the questions have been properly framed.

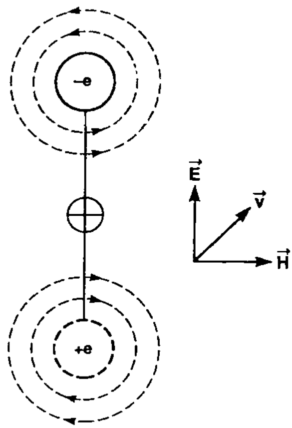

Fig. 4. The electromagnetic field lines of the P–$\overline{P}$ photon model of Fig. 3 as viewed in the laboratory frame of reference. The circularly polarized photon is rotating slowly in the plane of the figure, and is traveling forward (into the paper) at the velocity c. The electrostatic field lines run between the two dipole charges. The magnetic field lines are due to the forward motion of the dipole. As pointed out for example by Jackson [20], and as discussed in the text, these fields satisfy Maxwell's equations, and thus serve as a representation of the electromagnetic field associated with a photon.

5.c. Traveling Electric Dipoles

The photon is not generally regarded as carrying electric charges. In fact, the photon is customarily thought of today as a quantum that cannot be understood as any kind of a visualizable entity [15]. But the photon is in some manner the quantum of the electromagnetic field, and all of the electromagnetic fields that we know about are generated by electric charges (this is *Ampere's hypothesis* [26]). Thus it is certainly plausible to think of photons as carrying such charges. And, since the overall photon is electrically neutral, these charges must be in the form of (+,–) dipole pairs.

Sir William Bragg put forth the proposal in 1911 that electromagnetic waves carry actual electric charges [27]. This idea was developed mathematically by Bateman [16,17], who wrote in 1923 [28]:

> The original idea of the "neutral pair" of electric charges was that it consists of an electron neutralized by a positively-charged particle such as a proton, but ... it seems better to regard any electric charges that travel with waves of light as consisting of *an entirely different form of electricity which can travel with the velocity of light and still*

> *be associated with finite amounts of energy and momentum. There is nothing unreasonable in this supposition*, for the laws which determine the structures of the electron and proton may quite likely determine also a third form which can travel with the velocity of light and have either a positive or negative charge. (Italics added.)

Stuewer [29], in summarizing Bateman's work, noted that Bateman's equations for a dipole of electricity traveling at the velocity *c* have the E and H vectors normal to each other and to the direction of propagation, and that they satisfy Maxwell's equations for free space.

More recently, the problem of electric charges traveling at the velocity *c* was taken up by W. B. Bonnor. Bonnor first studied this problem from the point of view of the relativistic Maxwell equations [18]. His results are well-summarized in the abstract to his paper: "It is shown that Maxwell's equations admit solutions for charge moving with the speed of light. These are globally regular, but if the charge is of one sign only, the total energy is infinite. However, if equal amounts of positive and negative charge are present, the total energy can be finite, and such solutions seem physically unobjectionable." In a subsequent paper [19], Bonnor considered this problem in the context of general relativity. Again quoting his abstract: "I give solutions of the Einstein-Maxwell equations describing charge moving with the speed of light, *c*. The motion generates plane-fronted electromagnetic and gravitational waves. Charges moving parallel to each other with speed *c* do not interact; nor do they interact with parallel light beams." In these studies of systems moving along the z axis at the velocity *c*, Bonnor found it useful to replace the conventional (x,y,z,t) coordinates of relativity theory with the coordinates (x,y,u,v), where u = t - z and v = t + z (to within a numerical factor) [30].

An interesting discussion of electric charges moving at velocities close to *c* can be found in Jackson's book *Classical Electrodynamics* [20]. On pages 380 - 384, he derives the covariant electromagnetic equations (Eqs. 11.118) for an electric charge moving in the x_3 direction past a fixed observer. This charge gives rise to a transverse electric field E_1 in the x_1 direction, a transverse magnetic field B_2 in the x_2 direction, and a longitudinal electric field E_3 in the x_3 direction. Then he discusses how these equations behave as the charge approaches the velocity *c*: "Fields (11.118) exhibit interesting behavior when the velocity of the charge approaches that of light. First of all there is observed a magnetic induction in the x_2 direction. This magnetic field becomes almost equal to the transverse electric field E_1 as $\beta \rightarrow 1$. ... For $\beta \rightarrow 1$ the observer at *P* sees nearly equal transverse and mutually perpendicular electric and magnetic fields. *These are indistinguishable from the fields of a pulse of plane polarized radiation propagating in the x_3 direction* (italics added)." Then Jackson goes on to discuss the spurious longitudinal electric field E_3: "The extra longitudinal electric field varies rapidly from positive to negative (as the charge passes the observer) and has zero time integral. If the observer's detecting apparatus has any significant inertia, it will not respond to this longitudinal field. *Consequently for practical purposes he will see only the transverse fields* (italics added). This equivalence of the fields of a relativistic charged particle and those of a pulse of electromagnetic radiation will be exploited later ... ." Hence the notion of a photon that carries electric charges seems to be compatible with what we know about electromagnetic theory.

The electromagnetic force that exists between the co-moving charges in an electric dipole is derived, for example, in French's *Special Relativity* [21], pages 244 - 245. If the charges are initially stationary, the only force is the electrostatic force between them. Then, as the charge dipole is accelerated to relativistic velocities, the electric field due to each charge is compressed into the transverse plane, and the mutual electric force is increased by a factor of $\gamma = 1/\sqrt{(1 - v^2/c^2)}$. However, in addition to this attractive *electric* force between the two charges in the charge dipole, an offsetting repulsive *magnetic* force is now created due to the two moving charges, and this magnetic force is large enough to make the combined electric and magnetic forces into a net attractive force [31] that varies as $1/\gamma$. Thus, if we are allowed to extend these results to the velocity limit c, where γ becomes infinite, the force between the two charges vanishes. This same result was obtained by Bonnor [19], as mentioned above.

6. THE LABORATORY FRAME OF REFERENCE

When the rotating P–H and P–$\overline{P}$ electric dipoles shown in Figs. 1 and 3 are viewed in the laboratory frame of reference, there is both an electrostatic field due to the two electric charges and a magnetic field due to the *forward* motion of the charges [32]. As Jackson [20] pointed out, the transverse electric and magnetic fields due to a single charge moving at the velocity c are "indistinguishable from the fields of a pulse of plane polarized radiation ... ." He also noted that the longitudinal electric field associated with this moving charge cancels out for an observer, so that "for practical purposes he will see only the transverse fields." If we have a (+,–) pair of moving charges, as in an electric dipole, then the cancellation of the longitudinal electric field components of the two charges in regions where they overlap is even more complete. (There have been suggestions that in some cases a longitudinal magnetic field component may be observable [33 - 37].) Bateman [16] and Bonnor [18] have both demonstrated that a moving electric dipole is consistent with Maxwell's equations, and thus can serve as a representation for the electromagnetic aspects of the photon. The electromagnetic field associated with a moving dipole is illustrated in Fig. 4. What we have done in the present work is to associate specific masses with these charges, and thereby relate the electromagnetic aspects of the photon to its mechanical aspects. Relativistically, it is the inclusion of these masses that raises problems, as we now discuss.

Suppose we take the photon model displayed in Fig. 3 and view it in a (hypothetical) frame of reference where it is moving at a velocity $v < c$.

Then we can use the equations of special relativity to examine the relativistic behavior of its dynamical properties. The masses m and $\overline{m}$ of the particle states P and $\overline{P}$ appear calculationally in Eqs. (7) and (8). These masses vary relativistically as $\gamma = 1/\sqrt{(1 - v^2/c^2)}$. On the other hand, the rotational frequency ω shown in Eqs. (7) and (8) varies relativistically as $1/\gamma$ (due to the relativistic time dilation). The radius r in these equations, which is at right angles to the forward motion of the dipole, is relativistically invariant. Thus the outward centrifugal force, $m\omega^2 r$, varies relativistically as $1/\gamma$. The corresponding inward electromagnetic force between the two moving charges also varies relativistically as $1/\gamma$, as is demonstrated for example in French [21]. This means that the factor e^2 in Eqs. (7), (9) and (11) should be replaced by e^2/γ in the moving frame of reference:

$$(e^2)_{v=0} \quad \Rightarrow \quad (e^2/\gamma)_{0<v<c} \quad . \tag{18}$$

Hence the force equation for the states P and $\overline{P}$ is correctly satisfied for velocities $v < c$. The calculated spin angular momentum, $mr^2\omega$, is relativistically invariant. Thus the mass quanta P and $\overline{P}$ have the correct relativistic properties. The Planck energy term becomes

$$(\Delta)_{v=0} \quad \Rightarrow \quad (\Delta/\gamma)_{0<v<c} \quad . \tag{19}$$

The invariance properties of the hole states H and $\overline{H}$ are more speculative. We know from the equations of special relativity that there is complete symmetry between $+m$ and $-m$ mass states with respect to their relativistic properties [7]. Hence it seems reasonable to postulate that the hole states H and $\overline{H}$, which behave mechanically like negative masses (Eq. 4), follow the same special relativistic behavior (γ dependence) as the positive-mass states P and $\overline{P}$, but with reversed signs for the mass. If this is so, then the hole states H and $\overline{H}$ exhibit the correct relativistic behavior for linear velocities $v < c$. Experimentally, photon wave packets in a medium are known to travel at velocities $v < c$, although interference effects obscure the actual velocities of the constituents of the wave packet [14].

The problem we of course encounter here is that photons, except possibly while passing through media, do not travel with velocities $v < c$. They travel *at* the velocity c, where the Lorentz transformations cannot be directly applied, since γ becomes infinite. Thus, even though the above estimates of relativistic behavior are suggestive, they don't really tell us what is happening at the limiting velocity c. If the photon is traveling in the z direction at the velocity c, then the z and t coordinates in a Minkowski diagram coincide. Hence (x,y,z,t) coordinates are not appropriate in a special relativistic sense for massive bodies traveling at v = c. This is the reason that Bonnor [18,19] and others [30] have used (x,y,u,v) coordinates, where u = z - t and v = z + t.

Although we cannot directly calculate the relativistic transformations that take us from the co-moving *photon frame* to the stationary *laboratory frame*, we can, to within an unspecified value for γ, deduce these properties. Consider first the angular frequency ω. In the photon frame, a photon angular frequency ω_{ph} is determined from Eq. (9) when we assign a (photon frame) energy for the photon. In the laboratory frame, we cannot measure ω_{lab} for this same photon directly, but we can measure its velocity c and wavelength λ, thus yielding the experimental laboratory frame value $\omega_{lab} = 2\pi c / \lambda$. The key point here is that both of these values for ω, namely ω_{ph} and ω_{lab}, are *finite* and *non-zero*. Thus their ratio is a well-defined (albeit unknown) value. We define this ratio as

$$\gamma_x \equiv \omega_{ph} / \omega_{lab} \quad . \tag{20}$$

In the context of special relativity, taken at the limit v = c, we would have $\gamma_x = \infty$, which we know phenomenologically to be incorrect. Hence the "empirical" value for γ_x shown in Eq. (18) represents the "correct" way of going to the limit v = c. This does not represent a "refutation" of special relativity. Rather, it is an attempt to "empirically" extend it into a domain – the domain of masses and charges moving at v = c – which is outside of the region of validity of the standard relativistic formulation.

The radius r of the photon model is an invariant, since it is at right angles to the forward motion of the photon. The spin angular momentum of the photon, $mr^2\omega$ (Eq. 8), is also an invariant, since the Lorentz boost from the photon frame to the lab frame is orthogonal to the plane of the spin rotation. Thus, in line with Eq. (20), we have

$$m_{lab} = \gamma_x m_{ph} \quad . \tag{21}$$

It then follows that the centrifugal force, $m\omega^2 r$ (Eq. 7), varies as $1 / \gamma_x$. Hence the electromagnetic force F^{em} that balances the centrifugal force must correspondingly vary as $1 / \gamma_x$. We must have, in accordance with Eq. (18),

$$F^{em}_{lab} = F^{em}_{ph} / \gamma_x \quad . \tag{22}$$

The crucial task for the theoretical relativists then becomes one of determining the proper value for γ_x, as obtained in the limit v = c. We must have

$$1 \le \gamma_x < \infty \ . \tag{23}$$

A clue as to the manner of the breakdown of the Lorentz transformation equations in the limit $v = c$ can be obtained by studying Eqs. (18) and (22). As discussed for example in French [21], the electrostatic field of an electric charge, which is spherically symmetric in the co-moving photon frame, is flattened in the laboratory frame by a factor of γ^2 in both the forward and backward directions, and is enhanced in the transverse direction by a factor of γ. At the limit $v = c$, the electrostatic field in principle becomes infinitely thin. Thus in a traveling charge dipole, as envisaged here for the photon, the variation in the position of the second charge may be large enough that this charge does not, on the average, lie wholly within the infinitely flattened disk of the electrostatic field of the first charge. This has the effect of reducing the *electrostatic attraction* between the two co-moving charges. Also, the magnetic field that is produced by the forward motion of the first charge logically occurs *behind* the first charge, which means that its effect on the second charge (which can propagate no faster than c) may be less than the value calculated in special relativity. This has the effect of reducing the *magnetic repulsion* between the two co-moving charges. Until we can modify special relativity in such a way as to include these possible effects at the extreme relativistic limit $v \cong c$, we cannot reliably determine γ_x, and we cannot accurately relate the photon energy in the co-moving photon frame to the photon energy as observed in the laboratory frame.

7. DISCUSSION

In electromagnetic waves, the angular frequency of the zerons clearly derives from the angular frequency of the accompanying photon. In the case of the particle waves generated by a moving massive particle, a different mechanism is required. As Eq. (1) shows, we must relate the relativistic *mass* of the incident particle to the *angular frequency* of the corresponding phase wave. This can be accomplished by equating the electrostatic mass Δ of the zerons to the relativistic mass of the accompanying particle, where these quantities are calculated in the laboratory frame of reference (Eq. 19 with $\gamma = \gamma_x$). Particle waves have the added complication that the particle and the phase wave are at different velocities. (This situation is also observed for electromagnetic waves in a highly dispersive medium.) Thus the zeron wave quanta of the superluminal particle phase wave must interfere with one another and create a subluminal group-velocity wave packet as a secondary excitation process. Hence the matter waves that arise from finite-mass particles are more complicated that the electromagnetic waves that arise from freely-moving photons, although the same basic zeron excitation mechanism may apply to both.

The present electromagnetic results raise a number of problems – in particular, the question of transforming the calculations from the photon rest frame to the laboratory frame. But hopefully they will help to sharpen our understanding of particle-wave duality, and also to delineate the physical content of the quantum viewpoint known as physical reality.

REFERENCES AND NOTES

[1] F. Selleri, *Quantum Paradoxes and Physical Reality* (Kluwer Academic, Dordrecht, 1990).
[2] Ibid., p. 358.
[3] Ibid., p. 91.
[4] M. H. Mac Gregor, *The Enigmatic Electron* (Kluwer Academic, Dordrecht, 1992), p. 91.
[5] Ibid., Chap. 14.
[6] Ibid., Chap. 5.
[7] For a detailed discussion of the properties of negative masses, see Y. P. Terletskii, *Paradoxes in the Theory of Relativity* (Plenum, New York, 1968).
[8] B. Hoffmann, *Perspectives in Geometry and Relativity* (Indiana University Press, Bloomington, 1966), pp. 176 - 183.
[9] Ref. 7, p. 93.
[10] This relationship was pointed out to the author by a referee of the present paper.
[11] H. Goldstein, *Classical Mechanics* (Addison-Wesley, Cambridge 1950), p. 135; D. W. Sciama, *The Physical Foundations of General Relativity* (Doubleday, Garden City, 1969), pp. 6 - 11.
[12] In the case of the wave packet that accompanies a moving electron, which we also assume is composed of zerons, it can be shown from the equations of perturbative special relativity [M. H. Mac Gregor, *Lett. Nuovo Cim.* **44**, 697 (1985); *Found. Phys. Lett.* **1**, 25 (1988)] that the zeron mass must be very small but non-zero.
[13] T. H. Boyer, "The classical vacuum," *Sci. Am.* **251**, (8), 70 (1985).
[14] We can draw a rough analogy between the propagation of hole states *H*, which occurs via the successive filling in of the hole by its neighbors along the direction of motion, and the propagation of electromagnetic waves through a medium, which is pictured as occurring via the successive absorption and repropagation of photons by the molecules in the medium (see F. A. Jenkins and H. E. White, *Fundamentals of Optics* (McGraw-Hill, New York, 1976), pp. 703 - 704).
[15] R. H Stuewer, Ref. 17, p. 332, quotes Albert Einstein as follows: "All the fifty years of conscious brooding have brought me no closer to the answer to the question, 'What are light quanta?' Of course today every rascal thinks he knows the answer, but he is deluding himself."
[16] H. Bateman, Phil. Mag. **46**, 977 (1923).

[17] In Roger Stuewer's book *The Compton Effect: Turning Point in Physics* (Science History Publications, New York, 1975), p. 312, Harry Bateman is described by E. B. Wilson, a contemporary physicist, as "probably the most powerful and consistent mathematician now working in electromagnetic theory."
[18] W. B. Bonnor, *Int. Journ. Theor. Phys.* **2**, 373 (1969).
[19] W. B. Bonnor, *Int. Journ. Theor. Phys.* **3**, 57 (1970).
[20] J. D. Jackson, *Classical Electrodynamics* (Wiley, New York, 1962), pp. 380 - 384.
[21] A. P. French, *Special Relativity* (Chapman and Hall, New York, 1968), pp. 234 - 250.
[22] Particle Data Group, "Review of Particle Properties," *Phys. Rev.* **D45**, Part II, June (1992).
[23] R. A. Beth, *Phys. Rev.* **50**, 115 (1936); see, for example, B. Cagnac and J. C. Pebay-Peyroula, *Modern Atomic Physics: Fundamental Principles* (Wiley, New York, 1975), Ch. 11.
[24] A contrary viewpoint is set forth by H. C. Ohanian in his book *Principles of Quantum Mechanics* (Prentice Hall, Englewood Cliffs, New Jersey, 1990), p. 244, who asserts that the angular momentum is carried by the wave that accompanies the particle. This viewpoint seems untenable in experiments where a single photon passes through a double-slit type of experiment, with the accompanying wave packet being broken apart or "sieved" through a half-silvered mirror and later recombined.
[25] We could assign intrinsic "spins" of $\hbar/2$ to the P and H states, and then have zerons and photons represent $S = 0$ and $S = 1$ spin couplings, respectively. But the assignment of a spin to a "hole" state, especially when it has a continuously variable mass parameter range, seemed to the author to be less plausible than the alternate formalism presented here.
[26] R. P. Feynman in *The Quantum Theory of Fields* (Proceedings of the Twelfth Conference on Physics at the University of Brussels, October 1961) R. Stoops ed. (Interscience, New York, 1961), p. 84.
[27] W. H. Bragg, *British Association Report*, p. 340 (1911).
[28] Ref. 16, p. 908.
[29] Ref. 17, pp. 312 - 314.
[30] Also see W. Kundt, *Zeit. Physik* **163**, 77 (1961).
[31] If the co-moving charges have the same sign, then the electric force is repulsive and the magnetic force is attractive.
[32] The instantaneous *transverse* linear velocity $v = \omega r$ of the charges due to their rotational motion is small in the photon frame of reference, as shown in Eq. 11, and is even smaller in the laboratory frame of reference, as indicated in Eq. 20; hence it is disregarded here.
[33] M. W. Evans, *Physica* **B182**, 227 and 237 (1992) and **B183**, 103 (1993); *Mod. Phys. Lett.* **7**, 1247 (1993); *Found. Phys. Lett.* **7**, 67 (1994).
[34] M. W. Evans, in *Waves and Particles in Light and Matter*, A. van der

Merwe and A. Garuccio eds. (Plenum, New York, 1994).
[35] M. W. Evans, *The Photon's Magnetic Field* (World Scientific, Singapore, 1992).
[36] A. A. Hasanein and M. W. Evans, *Quantum Chemistry and the Photomagneton* (World Scientific, Singapore, 1994).
[37] M. W. Evans and S. Kielich, eds. *Modern Nonlinear Optics*, Vols. **85**(1), **85**(2), and **85**(3) of *Advances in Chemical Physics*, I. Prigogene and S. A. Rice, eds. (Wiley Interscience, New York, 1993/1994).

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