A Field-Based Model of the Photon: Lorentz-Covariant Quantization

Richard Oldani

Abstract

The macroscopic Maxwell equations, which quantum mechanics uses to define radiation fields, are shown to be in violation of the special principle of relativity. This is resolved by applying Maxwell's equations microscopically to each of the n constituent wave trains of a macroscopic wave. It is then shown that spontaneous emission may be accounted for by subjecting a bound electron to the combined influence of the n superimposed wave trains. If emission is induced by a coherent wave, then frequency-doubling phenomena are predicted. Several examples are cited, showing the pervasiveness of frequency doubling in nature. The evidence suggests further that quantum statistics is due to microscopic field fluctuations rather than photon counting. A manifestly covariant description of an electron transition is obtained in the form of a Lagrangian density, which is then quantized by applying appropriate limits of integration. A simple shift in these limits yields an independent field in free space, or photon, which is bounded by parallel surfaces separated by a distance equal to the wavelength and period. The implications of this photon model upon interference phenomena and the inverse square law are briefly discussed. A test of the inverse square law is proposed.

Key words: spontaneous emission, microscopic radiation fields, relativistic quantum mechanics, quantization, frequency doubling, inverse square law, photon, quantum electrodynamics, cutoff frequency, vacuum energy

1. INTRODUCTION[1]

The semiclassical theory of electromagnetic radiation uses classical field concepts to describe the influence of an external radiation field on a system of molecules. This provides a plausible and correct account of absorption and induced radiation fields, but not of spontaneous emission, which must be described by a quantum-mechanical treatment of the sources.(2) However, quantum mechanics describes source behavior statistically. This led Einstein to comment,(3) "I find the idea quite intolerable that an electron exposed to radiation should choose *of its own free will*, not only the moment to jump off, but also its direction. In that case, I would rather be a cobbler, or even an employee in a gaming house, than a physicist." We shall attempt to understand these questions more clearly in the discussions that follow by analyzing the interaction of a radiation field with a single molecule.

The behavior of a molecule during emission is described in the Hamiltonian and Lagrangian formulations of quantum mechanics by energy, even though observables are given in terms of field. Unitary transformations can cause different pictures to emerge, but energy remains the dominant physical variable throughout. The fields are later recovered by a second quantization of the wave-function. The question may be posed therefore whether anything is lost in transforming between descriptions by continuous field and discrete energy quanta. In other words, does transformation theory give a complete description of field quantization? Fields are always applied locally, whereas energy, as defined by the wave-function, may be nonlocal in its action. It is conceivable that a more fundamental understanding of source behavior can be achieved by adopting the field view throughout. We begin by analyzing the microscopic structure of a radiation field.

2. MICROSCOPIC RADIATION FIELDS

2.1 Theoretical Foundations

The electromagnetic wave that is detected macroscopically is believed to have the same fundamental structure as the microscopic fields of which it is composed.(4) However, detectors have surfaces containing large numbers of molecules that cause field fluctuations to be smoothed over and the radiation field to be observed through averaging processes. Therefore, even though Maxwell's equations are defined microscopically, they are applied to radiation fields by continuous functions whose space-time volumes are large compared to the wavelength and period in what are referred to as the macroscopic Maxwell equations. This approach does not take into consideration the instantaneous effects that transverse fields may have upon matter due to microscopic fluctuations. Because it includes macroscopically determined properties such as coherence and photon-counting statistics, a macroscopic wave singles out the laboratory frame as being preferred in a formulation of Maxwell's laws. Thus it may not be in conformance with the special principle of relativity, which states that all coordinate systems in uniform relative motion are equivalent for formulating the laws of nature. Einstein used this principle together with the absolute speed of light to justify the longitudinal Lorentz invariance of an electromagnetic wave.(5) It has not been applied to transverse fields, which interact at unknown speed.

The quantum-mechanical treatment of transverse radiation fields is given in terms of probability distributions in space and time of detection events that are recorded by photodetectors, film emulsion, or other detection devices. The statistical origin of these descriptions is viewed as fundamental, so that a physical cause is not specified, or in the case of spontaneous emission they have an undefined cause, the vacuum state. If instead a theory is desired that describes quantization locally in terms of field, it must specify the precise manner by which fields described on the microscopic level produce a macroscopic wave together with its statistical properties. In addition, it should give both an improved understanding of electromagnetic phenomena and experimental predictions that can be tested.

2.2 Wave Trains

Consider a radiation field consisting of n wave trains of frequency ω_0 traveling in the x direction, where each wave train is emitted by a single molecular oscillator. The oscillators emit randomly in space-time, causing wave trains to intersect the y, z, t plane at random positions. Whereas a bound electron is assumed to be spatially and temporally symmetric in its field, the wave train it emits is asymmetric. A formalism based on ideal measurements is required that is able to include these distinctions of field while maintaining the degrees of freedom of the system.

If the wave train is viewed as an independent field source, the transverse electric fields may be expressed as

$$\left|\vec{E}(\vec{r},t)\right| = E(r)\cos[kx - \omega_0 t + \varepsilon], \qquad (1)$$

where r is the distance from the wave axis. This equation differs from that of most field sources because though fields diminish with r as is usual they are directed perpendicularly to the plane formed by r and the wave axis, while magnetic fields are parallel to it. Vector notation on the left side of (1) refers to the laboratory frame. It is not used on the right side because the orientation of a single coordinate system in empty space has no meaning physically. Effects such as polarization must be defined relative to two or more microscopic coordinate systems for them to be meaningful.

The use of the wave axis as the origin of the electric field amplitude is necessary for a local theory of electromagnetic radiation, and it requires a fundamental change in our interpretation of an electromagnetic wave. Whereas the macroscopic wave varies periodically between positive and negative field values, the microscopic field does not have a preferred direction in the plane of oscillation yz so that *all fields carry the same sign*. This distinction between points of view is necessary because the wave train is conceived of here as behaving autonomously according to a local formulation of Maxwell's laws and the special principle of relativity such that each wave train contributes independently to the combined wave by linear superposition.

The wave train acts as a field source with time-averaged axial symmetry. Due to the transverse nature of the fields and the Lorentz contraction, fields that fall off as $1/r^2$ do not exist. Therefore the requirements of symmetry and special relativity theory suggest that the sinusoidal field amplitudes of a wave train extend to infinity, diminishing *linearly* with r. The fact that a photon may be instantaneously transformed by pair production into two fields of infinite extent lends support to the concept of an infinite lateral field. This is because in order for the transformation to be physically consistent there must be an infinite field already present to initiate it.

2.3 Radiation Fields

If the molecules of a radiating gas move independently of each other, then the gas has $3n$ spatial degrees of freedom. The generalized coordinates of the n particles, together with their time derivatives the generalized velocities, may be represented by a single point in $3n$-dimensional configuration space, where $3n + 1$ is now the number of independent coordinates necessary to define the state of the system.

In the case of the radiation field we shall limit our consideration to transverse electric field vectors traveling in the x direction. This reduces the number of independent coordinates needed to specify its state to $2n + 2$. Fewer coordinates cannot be used without introducing an external coupling or averaging process, thereby arbitrarily restricting the number of coordinate frames available to describe the field, in violation of the special principle of relativity. Thus the wave trains described by (1) are assumed to behave independently of the averaging effect of optical detectors. The combined macroscopic field of the n wave trains is due to superposition and is obtained by summing the effects of wave trains vectorially:

$$\vec{E}(\vec{r},t) = \sum_{i=1}^{n} \vec{E}_i(r)\cos[kx - \omega_0 t + \varepsilon]_i, \qquad (2)$$

where fields and amplitudes take on instantaneous but unobservable values. The intensity of the microscopic field at a point in space-time is determined by the relative phase of wave trains and their distance taken perpendicularly from each wave train's axis. The n transverse fields are combined vectorially in the yz plane so that field reinforcement and cancellation occur instantaneously in response to microscopic field values. In order for field intensity to be observed, the fields must be subjected to spatial and temporal averaging by detectors. However, fields that cancel when averaged may still be present at the microscopic level and can influence charged matter for times on the order of a wave period. It is hypothesized that these instantaneously acting microscopic fields correspond to what is referred to in quantum theory as the vacuum state $|0\rangle$ of the electromagnetic field (see, e.g., Ref. 6). It anticipates the need, which will be discussed later, to replace fictitious harmonic oscillators with real oscillators.

The n components in (2) describe instantaneous fields on the microscopic level. Since superposition amplifies field effects, microscopic fields may attain an observable level instantaneously and yet be unobservable macroscopically. Therefore it is important to analyze if instantaneous fields can influence matter and how this would differ from the influence of a spatially and temporally averaged macroscopic field. Although classical theory as presently formulated can be used to explain microscopic fluctuations and field superposition, it is inadequate for interpreting them. In subsequent discussions all fields will be assumed to act microscopically and instantaneously.

3. FIELD-INDUCED EMISSION

3.1 Frequency Doubling

Let a gas consisting of molecules with two allowable energy levels, an excited state $|2\rangle$ and a base state $|1\rangle$, be introduced into the monochromatic radiation field described by (2). The bound electron receives an electric field contribution from each of the wave trains that varies in duration, amplitude, and spatial orientation in the yz plane. Thus each of the wave trains is perceived by the electron as a pulsating electric field. The combined influence of all the wave trains is to exert a pulsating force upon the electron that randomly changes its strength and its direction in the yz plane.

It is well known that the emission of radiation with frequency ω_0 can be induced by incident photons of energy $E_2 - E_1 = h\omega_0$, that is, by stimulated emission. However, even when external radiation of frequency ω_0 is unavailable, transitions should be possible if the *instantaneous* field intensity is sufficient to raise the electron to a higher energy level. This may occur when the fields of the n wave trains are combined by superposition, yielding a microscopic field intensity that is much greater than that of any single wave. The combined field may then cause a transition such that the electron's energy increases by an amount $E_2 - E_1$. In other words, the electron transition converts field to energy by quantizing it in the form of a photon. Because energy is related to field by the relation $E = h\nu = hc/\lambda$, we may expect an observable relationship not only with respect to energy, but in the field properties as well. Therefore we shall forgo the customary nonlocal interpretation of emission in terms of harmonic oscillators in order to seek a *local* connection between the incident monochromatic radiation field and a single electron oscillator.

The time-averaged influence of a sinusoidal wave is to induce simple electron oscillation. Each wave lobe in one direction is balanced by a second lobe in the opposite direction. However, if the amplifying effect of superposition is just sufficient to raise the electron to a higher energy level, then quantization will occur. In fact, a coherent wave of appropriate frequency should resonate with the natural frequency of the electron between energy levels. In other words, the combined superposed fields first elevate the electron to a higher energy state and then allow it to fall back as the field direction changes. When the electron returns to the lower state, energy comes into independent existence in the form of a newly created photon.

Upon comparing a wave cycle to the cycle of an electron oscillator $|1\rangle \rightarrow |2\rangle \rightarrow |1\rangle$, we see that the quantization of a coherent wave leads to *a doubling of frequency*. One half cycle of the electron's oscillation yields one complete cycle of radiation, or photon, such that the frequency of the emitted radiation is double that of the driven electron oscillator. Thus the secondary radiation will have half the wavelength $\lambda_0 = \lambda/2$ and twice the frequency $\omega_0 = 2\omega$ of the resonant wave. If $h\omega_0$ is the only transition level available, then emission will be attenuated or cease entirely when $\lambda/2 < \lambda_0$.

The imprecision of detectors will make these emissions seem to occur spontaneously and randomly. It is hypothesized therefore that spontaneous emission in thermal sources is the result of instantaneous fluctuations of field at the local level such that the time and direction of a photon's release are exact even though they are indeterminate. Photon "entanglement" may be interpreted in terms of superposed instantaneous fields as *field intensity* that separates or divides (i.e., unentangles) when field sources separate. Thus in contrast to quantum mechanics a clear distinction is made between field intensity, which is continuous, and quantization, which is discrete. Field intensity is equal to the photon energy times the number of photons only in the macroscopic statistical view. In the microscopic view field intensity must be quantized by an electron transition(s) to be observed, but this need not happen.

3.2 Field-Induced Energy Transformation

Frequency doubling is most easily detected if it occurs in a large number of molecules simultaneously. This is possible by eliminating losses such that transitions occur *elastically*. In fact, frequency doubling has been achieved in just this situation by passing laser light through a crystal.[7] In the experiment the incident monochromatic radiation resonates with driven electron oscillators within the crystal to produce a monochromatic beam having twice the frequency. A variation of this phenomenon that has also been documented, "two-photon" absorption, is caused by the superposition of coherent waves having different frequencies. Due to the nonlinear nature of the output, both effects are described quantum mechanically; however, their prevalence is *linearly* dependent upon the intensity of the incident radiation. It suggests that these phenomena have a field-derived origin. Clearly both the classical and quantum properties of matter are necessary to explain the occurrence of frequency-doubling phenomena.

The extreme generality of the assumptions underlying field-induced emission suggests that it can occur anywhere in the electromagnetic spectrum. However, if it is observed in liquids and gases, it will be as an inelastic process with possibly distinct characteristics. We may seek evidence of driven electron oscillators that interact inelastically by looking for sudden, apparently discrete, increases in the flow of energy in response to a small or slowly increasing externally applied potential difference. Exactly these features are prominent in a wide variety of natural phenomena referred to as period doubling, where each doubling of period represents an increase in the total energy flow. We may interpret the period-doubling process as a doubling of the number of molecular transitions contributing to the energy flow in response to a very small externally applied potential. The most precise of the many experiments that document this phenomenon uses liquid helium to which a temperature difference of a mere 0.001°C has been applied.[8] The pattern of the amplitudes and frequencies for increasing energy flow (i.e., temperature difference) forms a spectrum that is analogous to the spectra of atomic emission.[9] Many other experiments exhibit the same type of periodicity in what is referred to as period doubling during the route to chaos. The energy changes are discrete but are so small as to cause them to be undetectable. Because they occur at the molecular level they demonstrate the prevalence of quantum phenomena in everyday experience, and we may conclude that classical laws describing continuous forms of energy are illusory. In other words, the continuity of classical laws is a result of the imperfect nature of the instruments of detection.

In light-scattering experiments the frequency of incident and scattered light is the same in the limit of high quantum numbers. For low quantum numbers the frequency of scattered light coincides with the characteristic transition frequencies of the atom. Since both the classical and quantum theories use the macroscopic Maxwell equations to describe radiation fields, the wave-packet model of photons is appropriate for describing these phenomena. However, light-scattering experiments also exhibit frequency doubling.[10] Because it has no clear physical interpretation, frequency doubling is often referred to simply as a classical harmonic. If instead we attribute it to the resonant superposition of waves, then it indicates that the incident light is partially coherent. Its prevalence in the scattered light may serve then as a measurement of the degree of coherence. The microscopic Maxwell equations are called for so that photons consist of a *single* wave cycle. By requiring bound electrons to react to the *instantaneous* microscopic field during field-induced emissions and indeed in all electromagnetic phenomena, we reject photon models that include coherence properties as a part of their description. Therefore we seek a model of the photon whose formal description is given in terms of the instantaneous evolution of fields.

4. RELATIVISTIC QUANTUM MECHANICS

4.1 Field Quantization

The Hamiltonian formulation of quantum mechanics was the first to be introduced because it is based upon classical equations of motion of nonrelativistic origin. The clarity that is gained by using the particle point of view is lost, however, in its description of fields that are introduced by means of fictitious harmonic oscillators. It has a further disadvantage since transitions between two states refer to the same time, causing space and time to be treated differently. Thus even though we know that emission is Lorentz invariant, the processes are described by noncovariant means. We wish to describe quantization by a manifestly covariant method that treats space and time equivalently.

The Dirac equation fulfills the requirements of a relativistic theory for spin-1/2 particles, or fermions. Electron transitions, including those of pair production, are obtained by a second quantization of the wave-function. However, the relativistic treatment of spin-0 particles, or bosons, is not discussed in the literature. This may be rectified if the creation of a photon during an electron transition can be described relativistically, i.e., in terms of instantaneous fields. We may refer to this as first quantization since it describes photon emission by the direct influence of field.

4.2 Lagrangian Formulation

4.2.1 Path Integrals

The initial and final states of photon emission are steady states, so that the coordinates are diagonalized. Moreover, we know from frequency-doubling phenomena that field-induced transition occurs in response to the instantaneous evolution of fields. Therefore it should be possible to describe emission, whether spontaneous or otherwise, as an exact process in four dimensions. The path integral formulation of quantum mechanics would seem to be an appropriate way of doing this since it uses ideal measurements and is expressed in relativistic form. It associates a probability amplitude with an entire motion of a particle as a function of time.(11) Let us examine how this method might be used to describe field-induced emission.

Consider a transition that proceeds from $|1\rangle$ at time T to $|2\rangle$ at time t and is caused by the superposition of fields. Then the trajectory that the electron follows initially is classical and may be described by Hamilton's principle of stationary action:

$$S[x(t)] = \int_T^t L[x(t), \dot{x}(t)]dt, \qquad (3)$$

where L is the Lagrangian. Although classical trajectories are characterized by stationary action, the minimum change in action for a transition is equal to $\hbar$. Thus the emission process $|2\rangle \rightarrow |1\rangle$ will result in a change in action $S_2 - S_1 = \hbar$.

Emission must be described quantum mechanically, meaning that states are defined over all space at a particular instant and the electron follows all paths in its return to the base state. The probability that the electron will be found in a given space-time region by an ideal measurement is made up of the sum of the contributions, or probability amplitudes, one from each of the paths in that region. A single path amplitude will serve to illustrate how these calculations are to be interpreted. We define the probability amplitude for an electron to leave from an initial position x_T in $|2\rangle$ and to arrive at a final position x_t in $|1\rangle$ to be

$$\langle x_t \,|\, x_T \rangle = \lim_{t\to 0} \int \exp(-i/\hbar) S[t, T, x(t)]dt, \qquad (4)$$

where $S[t, T, x(t)]$ is defined as in (3). This equation establishes a close formal relationship between classical and quantum mechanics for an emission process. The time t is continuous since it refers to sinusoidal variations in the photon's fields, while ε is the time interval between particle position measurements along the path. Thus t is an internally specified time that determines phase, while ε is determined in the laboratory frame. Because the electron follows all paths, contributions to photon creation arise from all points in space.

The Feynman path integral formulation (4) of spontaneous emission by a single molecule is based upon ideal position measurements and the existence of undetectable microscopic fields. Its quantum-mechanical counterpart, the Einstein A coefficient, gives the probability of emission from an ensemble of molecules. The Einstein B coefficient referring to stimulated emission is discussed elsewhere.(1)

4.2.2 Quantum Electrodynamics

The path integral method is not able to interpret emission in terms of the continuous evolution of fields because it is based upon the particle picture and employs singular fields. The use of field singularities and the uncertainty principle is therefore implicit to its description of emission processes. These are shown to be equivalent in Ref. 12. However, singularities are a constant source of difficulty in mathematical theories because they are nonphysical. Infinities are thereby introduced and must be eliminated by using the purely mathematical tool of renormalization. The fact that the removal of infinities cannot be accomplished in a more satisfying way is a continual source of irritation in physics.

Suppose that the basis for the path integral method, the probability of finding a particle in a particular region of space-time, is interpreted not as an ideal measurement but as a field property. In other words, we use as our guiding principle the idea that field properties and particle properties are different aspects of the same thing. In a field-based interpretation the contribution of a path, its probability amplitude, would be completely determined by the field or field geometry in that space-time region. The infinities in QED may then be removed in principle by replacing particle properties such as mass and charge with continuous, field-derived quantities. In a field-based interpretation the reason for a cutoff frequency is that at extremely small distances central force fields are no longer representative of particle dynamics. This would suggest that a two-particle model is not appropriate.[1] In the next section we will show how particle properties may be dispensed with completely, leading to a description of electron transitions based upon field alone.

4.3 Lagrangian Density

The path integral method of quantum electrodynamics cannot be formulated in a consistent way within the conceptual framework of ordinary space-time. To avoid the well-known difficulties associated with renormalization we seek to interpret the emission process by means of fields. Because the microscopic fields of an electromagnetic wave always carry the same sign, the influence of a radiation field upon a bound electron may be described by a Lagrangian density that is a function of the fields and their first derivatives. We apply Hamilton's first principle, giving the action integral for an arbitrary classical region of space-time Ω:

$$S(\Omega) = \int_\Omega L(\varphi_r, \partial_\mu \varphi) d\Omega, \qquad (5)$$

where the φ_r refer to radiation fields. The conventional method is to treat the system as having a continuously infinite number of degrees of freedom corresponding to the values of the fields φ_r, considered as functions of time.[13] The fields and the conjugate momenta are then subjected to canonical commutation relations.

In the case of frequency doubling the φ_r may be identified with the wave train fields given by (2). The superposed fields are confined to the *yz* plane so that they reduce to *n* fields at the location of the electron with 2*n* degrees of freedom. The fields are quantized by imposing boundary conditions determined by the steady states $|1\rangle$ and $|2\rangle$. The four-dimensional volume Ω is now bounded by two space-like "surfaces" of infinite extent, (X, Y, Z) at initial time T and (x, y, z) at final time t:

$$S(\Omega) = \int_{X,Y,Z,T}^{x,y,z,t} L(\varphi_r, \partial_\mu \varphi) d\Omega. \qquad (6)$$

The boundary conditions give the initial and final electron positions. This description is fundamentally distinct from that given by (4), where the classical and the quantum aspects of emission are inextricably intertwined. It shows how quantization evolves in two successive stages, the first in terms of classical fields and the second as a quantized field.

To complete our analysis of the emission process we seek a description of the photon in free space. This is accomplished by a suitable change of boundary conditions that allows it to be expressed as an independent entity. If, for example, the photon is emitted along the x axis, then its relative position is determined by the time of emission T and its speed c. The limits of integration are now given by the parallel surfaces (Y, Z, T) and (y, z, t), which are the physical delimitations of its field. The surfaces are spaced apart a distance $(X - x)$ and $(t - T)$, determining the wavelength and period, and the fields within these surfaces extend laterally to infinity.

In order to conform to a local application of Maxwell's laws and the special principle of relativity, the Lagrangian density that describes single photons must be sinusoidal with fields oriented oppositely in the *yz* plane. Single photons or wave trains cannot initiate a detection event because they induce symmetrically opposed fields that are canceled by the temporal and spatial averaging common to all detectors. Therefore field superposition is the only means available for initiating electron transitions in detectors. It is hypothesized that detection events in optical phenomena are *not* due to single photons or single wave trains, rather they are superpositions of field of the type described in Section 3.1. The discrete detection events in optics are viewed as discontinuities caused by the shell model of atoms rather than as properties of photons. Single photons detected in phenomena such as the Compton and photoelectric effects are attributed not to the effect of sinusoidal fields but instead to instantaneous exchanges of momentum that occur when the core of a photon strikes an electron, i.e., when $Y \approx Z \approx 0$.

5. CONCLUSION

5.1 Theory

The macroscopic Maxwell equations were introduced into quantum theory to describe the results of experiments that occur in the laboratory frame. This is in keeping with one of the founding principles of quantum mechanics that only what is observable should be included in a theory of nature.(14) However, the use of macroscopic fields in this way forgoes all possibility of introducing a microscopic viewpoint to interpret unobservable subquantum processes such as vacuum energy, frequency doubling, and period doubling. By extending the usefulness of quantum theory into the unobservable realm of microscopic fields, we achieve greater versatility and understanding of its statistical equations. This may allow quantum mechanics to be applied more incisively and in wider areas of research.

There are also theoretical reasons for avoiding the laboratory frame when formulating natural laws. In celestial mechanics data obtained and recorded in the laboratory frame caused astronomers to mistakenly use the geocentric system to explain the motions of planets. Much later it became evident that due to its greater simplicity the heliocentric system was in fact the correct frame of reference for describing planetary motion. In other words, a *field law formulated on Earth is then referred to the point of its physical origin, the Sun*. A more complete discussion may be found in Ref. 15. The same reasoning may be applied to quantum mechanics. Maxwell's equations, which were first defined and used in the laboratory frame, must then be referred to the point of physical origin, the field sources, to be interpreted. However, the electromagnetic waves that compose radiation fields are currently defined in free space independently of sources. We cannot obtain more from a wave equation than what is put into it initially. We conceive of particles as field sources, so unless the field laws are formulated relative to a source, or origin, it will be impossible to define a consistent photon model. Because wave and particle behavior are currently described separately, they must also be explained in distinct ways by using the duality and complementarity principles. We have avoided *ad hoc* explanations of this type by assigning an origin to microscopic fields, as required by the special principle of relativity.

5.2 Experiment

In contrast to quantum theory, the photon model proposed here allows for diffraction and interference effects to be accounted for by a *local* application of the conservation laws. The rays of light in a double-slit interference experiment are evenly distributed across the screen, indicating that momentum is locally conserved when photons pass through the slits. The intensity of fringes is determined by electron transitions due to superpositions of photons' fields, as in (2). Thus energy is conserved locally *at the point of electron transitions* rather than statistically in terms of the field intensity. In this way the field intensity, which is continuous, is clearly distinguished from the field energy, which is discrete. To demand that field be quantized before transition occurs is too restrictive since it would mean that only quanta of definite energy could cause transition.

The inverse square law for point sources must be reformulated to include a linear dependence that is determined by the linearly superimposed fields. This will be combined with the usual inverse square component due to the spherical distribution of rays. Thus it is predicted that an accurate test of the inverse square law will reveal that the light intensity of an incoherent point source decreases more slowly than expected. In fact, a linearly diminishing time-averaged component of starlight has already been observed in what is described as the "long versus short" anomaly.(16) Further tests of this effect may be carried out in the laboratory by comparing the intensity versus distance of coherent and incoherent point sources.

Received 29 April 2005.

Résumé

Les équations macroscopiques de Maxwell, que la mécanique quantique utilise pour définir les champs de rayonnement, sont montrées être dans la violation du principe spécial de relativité. Ceci est résolu en appliquant les équations de

Maxwell microscopiquement à chacun des trains de vague du constituant n d'une vague macroscopique. Il est alors montré que l'émission spontanée peut être expliquée en exposant un électron de limite à l'influence combinée des trains de vague du n superposé. Si l'émission est induite par une vague cohérente alors des phénomènes de fréquence double seront prédits. Plusieurs exemples sont cités montrant la force de persuasion de la fréquence double dans la nature. De plus, la preuve suggère que cette statistique quantique est due aux variations du champ microscopique au lieu d'un calcul de photons. Manifestement, une description de covariant d'une transition d'électron est obtenue sous forme d'une densité lagrangienne qui est alors quantifiée par l'application de limites d'intégration appropriées. Un changement simple dans ces limites produit un champ indépendant dans l'espace libre, où le photon, qui est limité par les surfaces parallèles séparées à une distance égale de la longueur d'onde et du temps. Les implications de ce modèle de photon sur les phénomènes d'intervention et de la loi de l'inverse du carré sont discutées brièvement. Un test de la loi de l'inverse du carré est proposé.

Endnotes

[1] This paper is primarily concerned with spontaneous emission. The question of stimulated emission is taken up in Ref. 1.

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Richard Oldani
2203 Clymer-Sherman Road
Clymer, New York 14724 U.S.A.