The zero point field and the reduction of the wave packet in semiclassical electrodynamics.

Jacques Moret-Bailly *

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Abstract

In the classical theory, an electromagnetic field obeying Maxwell's equations cannot be absorbed quickly by matter, so that it remains a zero point field. Splitting the total, genuine electromagnetic field into the sum of a conventional field and a zero point field is physically meaningless until a receiver attenuates the genuine field down to the zero point field, or studying the amplification of the zero point field by a source.

In classical optics all optical effects must be written using the genuine field, so that at low light levels the nonlinear effects become linear in relation to the conventional field. The result of the interpretation of all observations, even at low light levels, is exactly the same in quantum electrodynamics and in the semi- classical theory.

The zero point field is stochastic only far from the sources and the receivers; elsewhere, it is shaped by matter, it may be studied through fields visible before an absorption or after an amplification.

A classical study of the "reduction of the wave packet" extends the domain of equivalence of the classical and quantum zero point field; using both interpretations of this field makes the results more reliable, because the traps are different.

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1   Introduction.

Many physicists think that the zero point field is introduced by quantum electrodynamics (QED); historically, its knowledge is anterior to QED, and the computation of its mean amplitude by Planck [1] and Nernst [2] allowed the identification of the energy of the optical modes with the energy of quantum harmonic oscillators, which is the starting point of QED.

The interpretation of the zero point field is, however, fundamentally different in the classical theory and in QED: in the classical theory, the electromagnetic field is, in all points, a physical quantity and any solution of Maxwell's equations

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*Laboratoire de physique, Universit de Bourgogne, BP 47870, F-21078 Dijon cedex, France. email : Jacques.Moret-Bailly@u-bourgogne.fr

represents precisely an optical mode; in QED, the electromagnetic field is a mathematical tool substituted to the wave function of the photon, and the postulate "reduction of the wave packet"changes the mode corresponding to a photon, thus the electromagnetic field. This fundamental difference is generally not clearly set, even in the best books (Milonni [3]).

For a practical use, a confusion between the quantum and classical zero point fields is not important because as long as the reduction of the wave packet is not used, the equations are exactly the same; this similitude was well studied by Marshall and Santos [4] and previous authors; our aim is seeking after an extension of their work to other optical problems, finding, in particular, a classical equivalent to the reduction of the wave packet, so that it becomes possible to use either interpretation in all problems.

The choice between the classical and QED interpretations depends on the spirit of the physicist. Using the interpretations of both the classical (or semiclassical) and quantum electromagnetic theories increases the reliability of the explanations, each theory having its specific advantages and traps; QED introduces more compact computations, more results use it; classical electrodynamics requires more complicated computations, but it seems next to the experiments; as QED is more used than the classical theory, its traps appear more in the literature :

Confusing the two interpretations of the electromagnetic field, thus using wrongly the postulate "reduction of the wave packet", the best specialists of the quantum theory tried to discourage Townes from discovering the maser [5]. To avoid such errors Lamb and al. [6, 7] propose to reject the photon; in despite of their affirmation, is seems a *de facto* rejection of the principles of quantum electrodynamics.

For some physicists QED is useless in high field experiments: "The subtle interplay between real and imaginary parts of the complex linear and nonlinear susceptibilities follows quite naturally from the semiclassical treatment. How can this information be obtained from a theory in which the fields are quantified ? [...] The semiclassical theory which is used in this monograph will describe all situations correctly in a much simpler fashion"(Bloembergen [8]).

To describe correctly the semiclassical theory, we qualify the electromagnetic field as follows :

-"genuine"for the total electromagnetic field, with the genuine electric field noted $\widehat{E}$;

"zero point"for the field which remains after the largest, coherent, physically possible absorption of the genuine field; notation: E_0;

"conventional"for the genuine minus the zero point; as it is the commonly considered field, the conventional electric field will be simply written E;

"stochastic"for a stochastic zero point field.

Section 2 reminds the origin and properties of the classical fields, in particular the zero point fields.

Section 3 gives the correct relation between the signal of a photoreceiver and the electromagnetic field.

Section 4 applies the result of section 3 to the computation of the fourth order interferences.

Section 5 proposes a classical equivalent of the postulate "reduction of the wave packet".

2 Recall of the properties of the classical electromagnetic field.

As Maxwell's equations are linear in the vacuum, a linear combination of modes is a solution; with given limiting conditions, complete sets of modes allow to develop any mode. The energy of a mode is finite if its time and space extensions are limited; supposing that the mode is alone in the space, its energy is: $W = \int w(\nu) \mathrm{d}\nu$ where $w(\nu)$ is the energy $\frac{1}{2}\int(\epsilon_0 E^2 + \mu_0 H^2)\mathrm{d}v$ relative to the fields whose frequencies are between ν and $\nu + \mathrm{d}\nu$, at any instant. The usual normalisation is such that $\int \frac{w(\nu)\mathrm{d}\nu}{\nu} = h$. Two modes are orthogonal if the energy of their sum is the sum of their energies.

A punctual source S_O of electromagnetic field (i. e. the most general multipole) in a point O may be developed linearly using the derivatives of the three-dimensional Dirac's distribution δ_O:

$$S_O = \sum_{p,q,r \geq 0} f_{t,O,p,q,r}\partial_x^p\partial_y^q\partial_z^r\delta_O \tag{1}$$

where $f_{t,O,p,q,r}$ is a distribution relative to the variable t, and where $f_{t,O,0,0,0}$ is a constant.

Here the $f_{t,O,p,q,r}$ are supposed regular functions of time $f_{O,p,q,r}(t)$, and the number of non-zero $f_{O,p,q,r}(t)$ is supposed finite. For instance, the Oz oriented dipole of a molecule in O is proportional to the distribution $f_{O,0,0,1}(t)\partial_z\delta_O$, with, for instance $f_{O,0,0,1}(t) = \sin\omega t$.

The fields radiated by these multipoles at the point source O are mathematically singular in O, it is an approximation of the physical problem discussed later. These fields are often, improperly qualified "strictly spherical" although they are not invariant by a rotation around any axis Ou; the reason is that the fields on two spheres of centre O have the same dependence on the Euler angles while it is not the case for a beam focussed in O which diffracts.

Consider a particular source S_O, and the source S'_O obtained replacing $f_{O,p,q,r}(t)$ by $-f_{O,p,q,r}(-t)$; by a time inversion, the source S'_O becomes a source S_O^- which absorbs a "strictly spherical" field; summing the first and the last problems, S_O and S_O^- cancel, it remains a "strictly spherical" field F_O which converges to O then diverges. Thus, the light emitted by a multipole will be considered as produced by the evolution of a "strictly spherical" converging beam, without the multipole. This field F_O is regular everywhere, except in O.

The field F_O corresponding to S_O is absorbed if it is completely cancelled by an opposite field; this opposite field cannot be a linear combination of a finite number of fields $F_A, F_B, F_C...$ corresponding to multipoles placed in points

$A, B, C...$ different of O, because these fields are regular in O. Thus *the absorption of the electromagnetic field radiated by a point source requires an infinity of point absorbers, the residual field constitutes the zero point field.* The building of the zero point field shows that it is an ordinary field.

An objection to the previous mathematical description may be set:

The dipoles introduced in spectroscopy are not punctual; but their dimensions are supposed small in comparison with their distances, so that the conclusion remains approximately valid: the absorption of the field radiated by a small source requires a lot of small absorbers, a long time during which it remains a part of the field radiated by the dipole.

Far from sources, the zero point field E_0 is generated by a large number of sources supposed incoherent, so that it is stochastic, it is characterised by its mean amplitude. If an atom emits a photon (that is, in the classical theory, a wave corresponding to an energy $h\nu$), the radiated field, large near the atom, is not immediately compensated by propagation, diffusion or absorption; thus the fluctuations of the field are shaped by next or coherent sources, so that "stochastic" is not a sure property of the zero point field.

A macroscopic consequence of the structuring of the zero point field by matter is observed in the Casimir effect [9]: long wavelengths are rejected from inside two parallel plates, so that a lower pressure of radiation attracts the plates.

Following Einstein, the stimulated amplification of a mode by a source depends only on the amplitude of the true, genuine incident field $\widehat{E}$; the conventional, usual field $E = \widehat{E} - E_0$ is a purely mathematical object, it has no physical, individual existence.

Remark that the field radiated by a dipole is the same for an emission, a refraction or an absorption; in the last case the dipolar field cancels a part of an external field; the equality of Einstein's B coefficients for stimulated emission and absorption (demonstrated by thermodynamics) appears natural. The absorption of light is considered now as a decrease of the energy in a mode down to the zero point energy, the emission is an amplification of the energy in a mode; thus all systems are connected at least by the zero point field, even in classical physics isolated systems do not exist.

The oscillating dipole is a particular system of moving charges; any moving electron radiates a field, but if it belongs to a stationary system the interference of the radiated field with the zero point field does not change the energy of this last field, in the average. Sommerfeld's electron does not fall on the proton, but the fluctuations of its interaction with the zero point field produce the Lamb shift [10, 3].

Remark that the existence of the zero point field depends on the emission of an electromagnetic field by charged particles; if the charged particles are unable to emit a very high frequency wave, there is no zero point for high frequencies, no UV divergence.

Planck's constant h connects the density of zero point energy in the universe to microphysics; is h a cosmological or a microphysical constant?

3 Absorption and detection.

The signal of a photoelectric cell cannot be a function of the conventional field E which has no physical existence; for a long time, the sensitivity of the detectors of light was bad so that the zero point field could be neglected and the genuine field $\widehat{E}$ could be replaced by the conventional field

A light receiver is excited by an attenuation of the energy of a mode from a value higher than $h\nu/2$ to nearly $h\nu/2$. Generally this is possible if the mode was amplified by a source, but in the dark, cold, good photocells generate a noise signal which seems produced by the particularly large fluctuations of the zero point field.

The net available energy on a receiver is proportional to the difference between the input and output energies in the exciting mode; set E_0 the total zero point field received by the cell, and E'_0 the small fraction of this field amplified by the source, with an amplification coefficient $1 + \gamma$; the available energy on the source is

$$\widehat{E}^2 - E_0^2 = (\gamma E'_0 + E_0)^2 - E_0^2 = 2\gamma E'_0 E_0 + (\gamma E'_0)^2. \tag{2}$$

Usually E_0 is much smaller than $\gamma E'_0$, $2\gamma E'_0 E_0$ is neglected, the usual rule is got; on the contrary, supposing that γ is small, $(\gamma E_0)^2$ is neglected; for long observations, the time- average of the total zero point amplitude is zero, so that no signal is observed; for a short observation the phases are constant so that the detected signal is proportional to $\gamma E'_0$ that is to the amplitude , not the intensity of the conventional field, with, however, the additional factor E_0 which has an arbitrary phase. The phase factors of E_0 and E'_0 fluctuate almost independently: without a sophisticated detection nothing appears.

The classical emission or absorption is modelled by an excitation of a mono- or polyatomic molecule by an electromagnetic field up to a barrier between the two involved relative minimums of potential u_1 and u_2; if the initial and final states are stationary $|u_2 - u_1| = h\nu$. But our macroscopic experiments usually use nearly plane modes while the molecules emit light generally through dipoles or quadrupoles. Quantum mechanics transforms the geometry of the waves using the "reduction of the wave packet". Section 5 gives the classical reduction of the wave packet.

4 Fourth order interferences.

A sophisticated detection is performed in the fourth order interference experiments with photon counting: two elementary measurements are done while the phases of E_0 and E'_0 are constant (see, for instance, [11, 12, 13, 14, 15]). The result of these experiments is easily got *qualitatively* using the conventional rules [16], but the contrast of the computed fringes is lower than shown by the experiments. In the simplest experiment [12] two small photoelectric cells are put in the interference fringes produced by two point sources; the interferences are not visible because they depend on the fast changing difference of phase ϕ

of the modes of the zero point field amplified by the sources. The sources are weak; the signal is the correlation of the counts of the cells, so that the phases of E_0 and E_0' are eliminated.

Distinguishing the photoelectric cells by an index j equal to 1 or 2, set δ_j the difference of paths for the light received by the cells. The amplitude of the conventional field received by a cell is proportional to $\cos(\pi\delta_j/\lambda + \phi/2)$, so that, assuming the linearity in the conventional field, the probability of a simultaneous detection is proportional to

$$E_0^2 E_0'^2 \cos(\frac{\pi\delta_1}{\lambda} + \frac{\phi}{2}) \cos(\frac{\pi\delta_2}{\lambda} + \frac{\phi}{2}) \propto \cos(\frac{\pi\delta_1}{\lambda} + \frac{\phi}{2}) \cos(\frac{\pi\delta_2}{\lambda} + \frac{\phi}{2}). \quad (3)$$

The mean value of this probability got by an integration over ϕ is zero for $\delta_1 - \delta_2 = \lambda/2$, so that the visibility has the right value 1. Assuming the usual response of the cells proportional to the square of the conventional field, the visibility would have the wrong value 1/2 [17]. Equation 3 may be found directly computing the interference of the zero point modes amplified by the sources.

5   Classical reduction of the wave packet.

The reduction of the wave packet breaks the symmetry of the waves, transforming, in particular, a local wave into a beam, for instance a spherical dipolar wave into a plane wave.

The polarisation of a transparent matter by a light beam may be observed by a variation of the energy levels, or detecting Kerr effect,...Thus the beginning of a pulse of light must transfer energy to matter, and this energy is recovered in the tail of the pulse (except for a small incoherent Rayleigh scattering). In the tail, the field is amplified, although there is no transition, no inversion of population, the polarisation mixing only slightly the initial state of the molecules with other states. This power of amplification applies not only to the exciting mode, so that many modes, usually initially at the zero point, are amplified, later reabsorbed in the medium : there is a dynamical equilibrium between the exciting field, the other modes and the polarisation of the molecules. The modes which are excited are dipolar or quadrupolar, they radiate far only the small incoherent Rayleigh field : they may be qualified "local". On the contrary, the interactions with the light pulse are strong because they are coherent.

As the local modes are amplified, the strongest and longest fluctuations of their field may be able to excite molecules up to a barrier, such that an absorbing transition occurs; the mean energy of the local field, then of the molecules, is decreased, the amplification of the tail of the pulse is decreased, the medium has absorbed the light. In a laser, a similar process explains the coherent amplification by incoherently pumped molecules.

The emission of a field during the absorption of a quantum of energy is not instantaneous; during this emission and a short time after it, the probability for a strong and long fluctuation of the field is lowered, so that a sub-poissonian photon statistic appears; neglecting the space-time structuring of the field leads to the poissonian statistic [18, 19].

6 Low level "Impulsive Stimulated Raman Scattering"

Consider a nonlinear property which may be developed as a series of the electric field of an electromagnetic field. It must be a function of the genuine field. The development of this function using the conventional field is linear for low values of this field: there is a linearisation of the properties at low values of the conventional field.

If the property cannot be written as a series development, a specific treatment is necessary; consider, for instance the adaptation to the natural incoherent light of the "Impulsive stimulated Raman Scattering"(ISRS); ISRS is known since 1968 [20] and now commonly used [21, 22]. It is not a simple Raman scattering, but a parametric effect, combination of two *space-coherent* Raman scatterings, so that the state of the interacting molecules is not changed. The hot[1] exciting beam and its scattered beams interfere into a single frequency, redshifted, beam; the cold beam is blueshifted.

The interference of two collinear light beams into a single frequency beam is often performed involuntarily, for instance using a Michelson interferometer in with a moving mirror produces a Doppler frequency shift. The mixture of the frequencies requires an observation shorter than the beats of the two beams. The resulting frequency is intermediate, in proportion of the conventional amplitudes of the initial frequencies. In ISRS, the scattered amplitude which is permanently mixed with the incident amplitude remains extremely low and the Raman frequency is much lower than the exciting frequency, so that the relative frequency shift $\Delta\nu/\nu$ is nearly proportional to the conventional scattered amplitude and to the Raman frequency[2].

The conventional scattered amplitude is proportional to the square of the incident genuine amplitude, square which, at a low level, is proportional to the conventional amplitude. More simply, while at high intensities the scattered amplitude is stimulated, at low intensity it is spontaneous, but it remains coherent in the absence of collisions because the behaviour of all molecules on a wave surface is the same (just as in refraction). Thus, the relative frequency shift is nearly constant, only slightly modified by the dispersion of the tensor of polarisability.

ISRS is obtained using ultrashort light pulses, that is "pulses shorter than all relevant time constants"[23], usually femtosecond laser pulses. The relevant time constants in a gas may be adapted to incoherent light :

i) to avoid that the collisions destroy the coherence of the excitation of the molecules during the pulses, the pressure must be very low;

ii) to obtain an interference of the scattered and incident lights into a single frequency light, the period which corresponds to the virtual Raman transition

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[1]The temperature of a spectral line is deduced from Planck's laws

[2]Computing this interference process with the genuine amplitudes is more difficult because it is necessary to take into account the zero point field of the three involved modes.

must be larger than the length of the impulsions. The molecules must have transitions in the radiofrequencies, generally hyperfine transitions.

The Universe, provides good experimental conditions for a confusion of this interaction with a Doppler effect: the paths are long and the pressures often low, a lot of observed polyatomic molecules or atoms perturbed by Zeeman effect have hyperfine structures. The absorption spectra of the molecules which are destroyed at their first collision, H_2^+ for instance, cannot be seen because the redshift simultaneous with the absorption of their spectra widens, thus weakens, their lines.

7   Conclusion.

The electromagnetic fields, in particular the zero point field, often, improperly qualified "stochastic", obey the same equations in quantum and classical theories. Both, very different interpretations, are useful, giving the same final results, having their specific advantages : Quantum electrodynamics provides ready to use properties or postulates, but a common improper use of some of its concepts, the photon for instance, leads to wrong conclusions [6]; classical electrodynamics is more intuitive, but it requires often more complicated demonstrations.

An isolated system cannot exist in classical optics because the electromagnetic fields expand everywhere, although they are amplified or attenuated by matter.

The teachers should point the approximation made neglecting the zero point field and replace unnecessarily approximate rules, for instance the first Planck's law, by the rigorous rules.

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