

The zero point field in low light level experiments.

Jacques Moret-Bailly *

December 17, 2001

Abstract

The existence of the zero point electromagnetic field in the dark is a trivial property of classical electromagnetism. Splitting the total, genuine electromagnetic field into the sum of a conventional field and a zero point field is physically meaningless. If a receiver attenuates the genuine field down to a zero conventional field, it remains a zero point field having the coherence and the phase of the conventional field, and vice-versa for the amplification of the zero point field by a source.

Nonlinear optical effects must be written using the genuine field, so that at low light levels they 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.

Two examples are given : the computation of fourth order interferences and the use of the impulsive stimulated Raman scattering with ordinary incoherent light in astrophysics.

pac42.25Bs, 42.50Gy

1 Introduction.

The electromagnetic field radiated by an oscillating dipole, studied by Hertz in the nineteenth century, gives a particular solution of Maxwell's equations with a singular point at the origin. A linear development of this solution using solutions regular at the origin requires an infinite number of solutions. More physically, adding the solution for the dipole and another solution, the total energy may be higher, equal or lower than in the second solution, that is the dipole emits, refracts or absorbs energy; the last case corresponds to a partial cancellation of the exciting field by the field emitted by the dipole; this superposition of waves shows that while an oscillating dipole refracts or absorbs a part of the

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

energy radiated by an other dipole, it diffracts a large fraction of this energy. Both demonstrations show that, in a semi-classical theory, the absorption by atoms of the light emitted by other atoms is slow, it remains a residual field named now the zero point field. While the existence of this field is trivial, the computation of the mean value of its intensity $h\nu/2$ per monochromatic mode, by Planck and Nernst [1, 2], was difficult.

The oscillating dipole is a particular system of moving charges; any moving electron radiates a field, but if it belongs to a stationary system, in the average, it does not radiate energy: Sommerfeld's electron does not fall on the proton, but the fluctuations of its perturbations by the zero point field produce the Lamb shift [3].

The building of the zero point field shows that it is an ordinary field; thus it may be amplified by a source; the starts of the laser pulses show that a spontaneous emission is exactly the amplification of the zero point field.

In this paper we qualify the electromagnetic field as follows :

- "genuine" for the total electromagnetic field;

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

"conventional" for the genuine minus the zero point;

"stochastic" for a stochastic zero point field.

For a long time, the sensitivity of the detectors of light was bad so that the zero point field is neglected in the conventional classical electrodynamics; in modern optics, the "genuine field" \hat{E} is the sum of the "conventional field" E and the zero point field E_0 ; consequently the sensitivity of the photosensors is revisited in section 2. A consequence is the correct classical computation of fourth order interferences in section 3.

The semiclassical 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 W_1 and W_2 ; if the initial and final states are stationary $|W_2 - W_1| = h\nu$ ¹. 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 4 gives the classical reduction of the wave packet.

"Stochastic electrodynamics" is often used to avoid confusing the genuine with the conventional classical electrodynamics. Section 5 shows that this name is not very convenient because while the zero point field is stochastic far from the sources and the absorbers, this field is shaped by the sources and the absorbers.

The semi-classical theory is often preferred to quantum electrodynamics in nonlinear optics because it appears simpler and more concrete. The equivalence of the results provided by both theories, showed by Marshall & Santos [4] disappears only if the zero point field is neglected. As an example, section

¹As a monochromatic function is physically meaningless, we should write $\int \frac{e(\nu)d\nu}{\nu} = h$, with $|W_2 - W_1| = \int e(\nu)d\nu$

6 describes a light matter interaction whose ignorance by the astrophysicists seems a consequence of the difficult use of quantum electrodynamics, while the right classical electrodynamics leads easily to a result which could avoid to look for astonishing objects in the universe.

2 Absorption and detection.

Usually, we write that the intensity absorbed or detected by a photocell is proportional to the square of the amplitude of the conventional electric field, this square being proportional to the conventional flux of electromagnetic energy. This supposes that there is no coherence between the conventional field and the zero point field, an assumption which is false because a spontaneous emission is an amplification of a mode of the zero point field (see section 4). The equations of absorption must fulfil two conditions: i) be written using only genuine fields (which may be zero point fields); ii) preserve the zero point field in the average. As a zero point field included in the genuine field is absorbed, an equivalent field must be reemitted (or the genuine field is attenuated down to the zero point field). Remark that in the dark, cold, good photocells generate a noise signal which seems produced by the fluctuations of the zero point field.

The net available energy on a receiver is proportional to

$$\hat{E}^2 - E_0^2 = (\beta E_0)^2 - E_0^2 = 2(\beta - 1)E_0^2 + ((\beta - 1)E_0)^2. \quad (1)$$

Usually E_0^2 is neglected, the usual rule is got; on the contrary, supposing that β is nearly one, $((\beta - 1)E_0)^2$ may be neglected; for a given optical configuration, the time- average of the zero point amplitude is constant, so that the detected signal is proportional to $(\beta - 1)E_0$ that is to the amplitude of the conventional field, with E_0 as reference of phase. With an incoherent source, the phase factor fluctuates: without a sophisticated detection nothing appears.

3 Fourth order interferences.

A sophisticated detection is performed in the fourth order interference experiments with photon counting: two elementary measurements are done while the phase is constant (see, for instance, [5, 6, 7, 8, 9]). The result of these experiments is easily got *qualitatively* using the classical rules [10], but the contrast of the computed fringes is lower than shown by the experiments. In the simplest experiment [6] 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.

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

$$\cos\left(\frac{\pi\delta_1}{\lambda} + \frac{\phi}{2}\right) \cos\left(\frac{\pi\delta_2}{\lambda} + \frac{\phi}{2}\right). \quad (2)$$

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 [11].

4 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 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 its tail (except for a small incoherent Rayleigh scattering). Thus, 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 an 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 of 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 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.

5 Is the zero point field stochastic ?

Whichever their far or close origin, the electromagnetic fields are mixed, so that splitting the electromagnetic field into the zero point field and the conventional field is physically meaningless; this splitting is an anticipation of the interaction of the field with a receiver able to extract from the mode all available energy. A pure, stochastic zero point field exists only far from sources, in the dark, coming from many far incoherent sources. On the contrary, the field emitted by a molecule which radiates or absorbs energy is, near the molecule, mostly the

field of an oscillating dipole or quadrupole; even if an absorption re-establishes the mean value of the zero point field, the field is shaped by the molecule near it, not stochastic. Using the results of the previous section, this property extends to the modes of collimated beams; if a sheet of dark glass reduces the conventional intensity of a beam to zero, the phase of the beam remains written in the remaining zero point field.

A macroscopic consequence of the structuring of the zero point field by matter is observed in the Casimir effect [12]: long wavelengths are rejected from inside two parallel plates, so that a lower pressure of radiation attracts the plates.

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 an extraordinarily 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 a poissonian statistic [13, 14].

Squeezing is also an elementary observation of a non-stochastic zero point field.

6 Low level "Impulsive Stimulated Raman Scattering" (ISRS).

Quantum electrodynamics leads to consider the photon not only as an amount of energy but as a particle too; although this last concept is sometimes considered as dangerous and rejected [15], this concept led the astrophysicists to reject light-matter interactions as an alternative to the Doppler effect to explain observed redshifts of far objects. It is a rejection of coherent interactions.

ISRS, known since 1968 [16] is now commonly used [17, 18]. It is not a simple Raman scattering, but a parametric effect, combination of two *space-coherent* Raman scattering, so that the state of the interacting molecules is not changed. The hot ² exciting beam and its scattered beams interfere into a single frequency, redshifted, beam; the cold beam is blueshifted.

ISRS is obtained using ultrashort light pulses, that is "pulses shorter than all relevant time constants" [19], usually femtosecond laser pulses. As it has no intensity threshold it works with the light pulses which make the ordinary incoherent light. 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, 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 must be larger than the length of the impulsions. The molecules must have transitions in the radiofrequencies, generally hyperfine transitions.

²The temperature of a spectral line is deduced from Planck's laws

Decreasing the intensity of the beams down to a value for which \hat{E} is not much higher than E_0 , the Raman scattered conventional amplitude A proportional to the intensity writes

$$A \propto \hat{E}^2 - E_0^2 = (\beta E_0)^2 - E_0^2 = 2(\beta - 1)E_0^2 + ((\beta - 1)E_0)^2. \quad (3)$$

The last term may be neglected, the first, proportional to the incident amplitude, represents the usual spontaneous coherent Raman amplitude; the interference reduces the incident and scattered wave vectors into a single wave vector, so that the scattered light is not on a cone as in usual laser coherent Raman experiments.

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 mono- or polyatomic molecules, perturbed by Zeeman effect which are observed 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 of their absorption spectra widens, thus weakens, their lines.

Similarly, all optical effects become linear at low light levels.

7 Conclusion.

The zero point field, often, improperly, qualified "stochastic" is a trivial component of the genuine classical electromagnetic field. An artificial subtraction of this field leads to the conventional classical electromagnetism, breaking the equivalence of the classical and quantum electrodynamics.

Many authors tried to demonstrate that the semi-classical theory is not correct at low light levels; their demonstrations use the conventional classical electrodynamics which is an approximation of the genuine classical electrodynamics; this approximation fails at low light levels.

Quantum and classical electrodynamics have 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 [15]; classical electrodynamics is more intuitive, but it requires often more complicated demonstrations. It is so common and useful to use both theories than some physicists think that the zero point field is introduced by quantum electrodynamics !

The teachers should replace unnecessarily approximate rules, for instance the first Planck's law, by the rigorous rules.

References

- [1] Planck, M., 1911, *Verh. Deutsch. Phys. Ges*, **13**, 138
- [2] Nernst, W., 1916, *Verh. Deutsch. Phys. Ges*, **18**, 83

- [3] Power, E. A., 1966, *Am. J. Phys.* **34** 516
- [4] Marshall, T. W. & E. Santos, 1988 *Found. Phys.* **18** 185; 1989, *Phys. Rev. A* **39**, 6271
- [5] Clauser J. F. , Horne M. A. , Shimony A. & Holt R. A. , 1969, *Phys. Rev. Lett.* ,**23**, 880
- [6] Gosh R. & Mandel L. , 1987, *Phys. Rev. Lett.* ,**59**, 1903
- [7] Ou Z. Y. & Mandel L. , 1988, *Phys. Rev. Lett.* , **61**, 54
- [8] Ou Z. Y. & Mandel L. , 1990, *J. Opt. Soc. Am.* , **7**, 2127
- [9] Kiess T. E. , Shih Y. H. , Sergienko A. V. & Alley C. O. , 1993, *Phys. Rev. Lett.* , **71**, 3893
- [10] Moret-Bailly J. , 1994, *J. Optics*, **25**, 263
- [11] Mandel L, 1983, *Phys. Rev.* **28**, 929
- [12] Casimir, H. B. G., 1948, *Proc. K. Ned. Akad. Wet.*, **51**, 793
- [13] Short R. & Mandel L. 1983, *Phys. Rev. Lett.* **51**, 384
- [14] Glauber R. J. 1966. in *Physics of Quantum Electronics*, Kelley P. L. et al. ed. McGraw-Hill, New York, 788
- [15] Lamb W. E. Jr., 1995, *Appl. Phys.*, **B60**, 77
- [16] Giordmaine, J. A. , M. A. Duguay & J. W. Hansen, 1968, *IEEE J. Quantum Electron.*, 4, 252
- [17] Yan Y.-X., Gamble E. B. Jr. & Nelson K. A. , 1985, *J. Chem Phys.* **83**, 5391
- [18] Nelson K. A. & Fayer M. D., 1980, *J. Chem. Phys* **72**, 5202
- [19] Lamb, G. L. Jr., 1971, *Rev. Mod. Phys* **43** , 99
- [20] Moret-Bailly J. 1998, *Quantum and Semiclassical Optics* **10**, L35
- [21] Moret-Bailly J. 2001, *J. Quantit. Spectr. & Radiative Ttransfer* **68**, 575