Linearisation of optical effects at low light levels.

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Abstract

As a light beam is produced by an amplification of modes of the zero point field in its source, this field cannot be distinguished; consequently a nonlinear optical effect is a function of the total field. However, we generally prefer to use a conventional field which excludes the zero point field; for a low conventional field, the total field may be developed to the first order, so that the effect appears linear.

This nearly trivial remark allows a correct computation of the signal of a photocell used for photon counting and shows that the "impulsive stimulated Raman scattering" (ISRS), a nonlinear, without threshold effect, which shifts the frequencies, becomes linear at low light levels, so that the shifted spectra are not distorted.

Comme un faisceau de lumire rsulte d'une amplification de modes du champ du point zro par sa source, le champ du point zro ne peut tre distingu ; en consquence, un effet optique non- linaire est une fonction du champ total. En prenant la dfinition usuelle du champ qui exclut le champ du point zro, pour un champ usuel faible le champ total peut tre dvelopp au premier ordre, de sorte que l'effet devient linaire.

Cette remarque quasiment triviale permet, en particulier, de rendre compte correctement de la dtection de la lumire d'un photorcepteur en "comptage de photons", et de montrer que la diffusion Raman impulsionnelle stimule, effet quadratique sans seuil, se transforme, bas niveau en un effet linaire qui fait glisser les frquences spectrales sans distordre les spectres.

pacs42.25Bs, 42.50Gy

1 Introduction

Introduced by quantum electrodynamics, the zero point electromagnetic field appears as a strange physical concept. The transformation of the first (wrong) Planck's law into the second [1, 2] sets its value $h\nu/2$, but not its nature.

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Stochastic electrodynamics [3] describes the zero point field, renamed "stochastic field" as an ordinary field, but the strongest (although qualitative) interpretation, is provided by the old classical theory : The electric field radiated by an oscillating electric dipole is known; if there is no external field, the dipole is a source; but if it is merged in an external field of the same frequency, with convenient polarisations and phases, it partly cancels the external electromagnetic field, decreasing the electromagnetic energy : the dipole is a receiver ; as a large part of the fields is not cancelled, the dipole not only absorbs a part of the incident field, it scatters it. Thus, the absorption of the field emitted by a dipole requiring an infinite number of dipoles, it exists a stochastic unabsorbed, scattered field. This description shows that the zero point field is an ordinary field. The measure of the Einstein coefficients A and B for the spontaneous and stimulated emissions shows that the spontaneous emission is exactly induced by the zero point field. Thus the field in a light beam is a zero point field amplified by a source, and it is artificial to distinguish in it a zero point field and the remainder, the field radiated spontaneously in the old theory (thereafter the conventional field). Thus the conventional field has no physical existence, it must not appear in the formula describing an optical effect.

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 considered proportional to the flux of electromagnetic energy. This supposes that there is no coherence between the conventional field and the stochastic field, an assumption which is false. How can we write that in the dark there is no absorption while the stochastic intensity hits a photoelectric cell ? A solution is supposing that there is an equilibrium between the absorbed stochastic field and a reemission. Remark that in cold, good photocells it remains a signal which seems produced by the long and powerful enough fluctuations of the stochastic field. E_0 being the amplitude in a mode of the stochastic field and βE_0 the field resulting of an amplification of this mode by a source, the net available energy on a receiver is $(\beta E_0)^2 - E_0^2 = 2(\beta-1)E_0^2 + ((\beta-1)E_0)^2$.

If β is nearly one, the second term may be neglected ; for a given optical configuration, the time- average of the stochastic amplitude $E_0^2 = |E_0|^2$ is constant, so that *the detected signal is proportional to the amplitude of the conventional field*. On the contrary, for a high conventional field, the usual rule is got.

This result is experimentally verified by the fourth order interference experiments with photon counting (see, for instance, [4, 5, 6, 7, 8]). The result of these experiments is easily got *qualitatively* using the classical rules [9], but the contrast of the computed fringes is lower than shown by the experiments. In the simplest experiment [5] 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 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, the probability of a simultaneous detection is proportional to

$$\cos(\frac{\pi\delta_1}{\lambda} + \frac{\phi}{2})\cos(\frac{\pi\delta_2}{\lambda} + \frac{\phi}{2}). \qquad (1)$$

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.

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

ISRS, known since 1968 [10] is now commonly used [11]. 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. ISRS is obtained using ultrashort light pulses, that is "pulses shorter than all relevant time constants" [12], usually femtosecond laser pulses. In a gas, the relevant time constants are:

i) the collisional time : the collisions destroy the coherence of the excitation of the molecules.

ii) the period which corresponds to the virtual Raman transition : the scattered light interferes with the exciting light into a frequency-shifted single beam so that the time-coherence of the output beams is not broken by the dispersion and the effect is strong.

ISRS is generally performed using at least a strong pump laser beam so that it is nonlinear, the frequency shift depends on the intensity of the beam. But it has no threshold : a direct study [13, 14] shows what happens if the pump beams are usual incoherent light beams, made of relatively long, weak pulses : the effect becomes linear so that the relative frequency shift $\Delta\nu/\nu$ depends slightly on a dispersion, not the intensity. The coherence preserves the wave-fronts; thus there is no blur either in the images or in the spectra, just as by a Doppler frequency shift. Thought the coherence of the effect called "Incoherent Light Coherent Raman Scattering" (ILCRS) makes it strong, it requires so low pressures that it seems impossible to perform it in the labs. The Universe, however provides good experimental conditions : the paths may be long, a lot of mono- or poly-atomic molecules have hyperfine structures providing the low energy Raman transitions : atoms perturbated by Zeeman effect near the quasars, H_2^+ molecules in the clouds detected by the forbidden nuclear spin transition of H_2 at 0.2m…

A part of the redshifts attributed to Doppler (or expansion) effect is surely provided by ILCRS able to transfer energy from high frequencies to isotropic thermal radiation (2.7K). Near bright stars, this transfer may be similar to a transfer by heated dust.

4 Conclusion

The nonlinear light-matter interactions without threshold become linear using weak light beams. In two examples, this trivial property provides an interesting expansion of well known effects; it explains many other effects, for instance the computation of the sub-Poissonian statistics in photon counting [15] is easier than the quantum computation [16] in particular in an intermediate case where the light flux is too large.

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