The zeropoint field — no longer a ghost.

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Abstract

We develop a local realist analysis of parametric down conversion, based on the recognition that the pump field, instead of down converting spontaneously, does so through its nonlinear coupling with a real zeropoint, or “vacuum” electromagnetic field. The theory leads to the prediction of a new phenomenon — that, in addition to the main down-conversion rainbow, there is a satellite rainbow, whose intensity is about 3 per cent of the main one. Confirmation of this prediction will call seriously into question the current description of the light field in terms of photons.

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1 Introduction

Light is nowadays widely believed to be made of photons, that is discrete packets of energy $\hbar \omega$, where $\hbar$ is Planck’s constant divided by $2\pi$. This is ironic, because Max Planck actually opposed quite strongly the concept of light quanta from 1905, when Albert Einstein first proposed them (as a “heuristic” hypothesis), and for at least 12 years thereafter. Planck also proposed, in 1911, the concept of a real zeropoint electromagnetic field, which he offered explicitly as an alternative to the light quanta. Planck’s constant enters into this theory in the role of the scaling of the zeropoint spectrum. In 1951 Einstein himself conceded that there was something very peculiar about photons, when he said “Nowadays every Tom, Dick and Harry thinks he knows what a photon is, but he is wrong”. So, finally, Planck and Einstein perhaps came close to agreement. The peculiarities referred to by Einstein have since become much more acute, to the extent that even supporters of the photon concept are now using words like “mind boggling” and “absurd” to describe their properties.

The properties of photons which have merited the description of “absurd” originate in a certain strange behaviour of all quantum particles, first pointed out in 1935 by Einstein, Podolsky and Rosen and by Schrödinger, and
known nowadays by the general term entanglement. According to this, if a pair of quantum particles is prepared in a superposition state, then a measurement made on one particle causes an instantaneous change in the state of the other, which means that quantum mechanics is in conflict with Special Relativity. It is curious that the only real experimental support for this strange set of events comes from such ephemeral “particles” as photons; reliable evidence from such as atoms, electrons and nuclei has steadily evaded us so far. I shall show that, at least in the substantial experimental domain of parametric down conversion (PDC), there is a rational and consistent theory of light, based on Planck’s concept of the zeropoint field, in which photons are entirely absent. Indeed it may be claimed that we are returning to the unquantized Maxwell theory of light.

2 The photon description of PDC

PDC occurs when a beam of coherent light from a laser, often referred to as the pump, is incident on a nonlinear optical crystal. A rainbow emerges from the crystal, each frequency, or colour, being emitted in a certain direction. More specifically, if the pump frequency is \( \omega_0 \), then the PDC rainbow contains all frequencies less than \( \omega_0 \), and the angle at which a given frequency \( \omega \) emerges depends on \( \omega \) and \( \omega_0 \). For example, if the pump’s wavelength is 300nm, which is in the near ultraviolet, and the crystal is potassium dihydrogen phosphate (KDP), then the down converted light at 450nm, which is blue, will be at an angle of 8.2 degrees to the pump, while that at 600nm (yellow) will be at 10.5 degrees, and that at 900nm (near infrared) at 16.6 degrees.

The photon description of PDC is disarmingly simple. A pump photon \( \hbar \omega_0 \) down converts spontaneously into a pair of photons, \( \hbar \omega_1 \) and \( \hbar \omega_2 \), with \( \omega_1 + \omega_2 = \omega_0 \). So there are certain pairwise correlations (see Fig.1) between the rays of down converted light. The angle \( \theta_1 \) at which the photon \( \omega_1 \) is emitted is determined through the requirement that the total momentum carried by the photon pair is equal to the momentum of the pump photon, that is

\[
h\omega_1 \sqrt{n_1^2 - \sin^2 \theta_1} + h\sqrt{\omega_1^2 n_2^2 - \omega_1^2 \sin^2 \theta_1} = h\omega_0 n_0 ,
\]

or alternatively

\[
\omega_1^2 \sin^2 \theta_1 = -\frac{1}{4} n_0^2 \omega_0^2 + \frac{1}{2} (n_1^2 \omega_1^2 + n_2^2 \omega_2^2) - \frac{1}{4 n_0^2 \omega_0^2} (n_1^2 \omega_1^2 - n_2^2 \omega_2^2)^2 ,
\]

where \( n_i = n(\omega_i) \) is the refractive index of the crystal at frequency \( \omega_i \). The appropriate values of \( n_i \), leading to the values of \( \theta_1 \) quoted above, were obtained from [3], Table 16.3. Note that, in order for this equation to be satisfied, the pump must be polarized so that it travels through the crystal as an extraordinary ray, which then gives \( n_0 \) less than \( n_1 \) and \( n_2 \). The down converted signals have been taken to be ordinary rays, which means we are dealing with Type-I PDC.
The price paid for the simplicity of this photon description is the entanglement of the photon pairs [10, 11, 12], which leads us precisely to the “mind boggling” and “absurd” consequences referred to in the previous section. This price is too high; indeed Einstein [13] argued that it was an abandonment of science! We shall show in the next section that such an abandonment becomes unnecessary once we substitute Planck’s zeropoint field for Einstein’s photons.

3 The field description of PDC

We have shown, in a series of articles [14, 15, 16, 17], that the above “photon entanglements” may be consistently explained as correlations between the wave modes of the light field. If we accept Einstein’s verdict on the photon “explanation”, we may indeed claim that ours is the only valid explanation of the whole body of data! The correlations in question arise because the corresponding modes of the zeropoint field (see Fig.2) are coupled together inside the pumped crystal. I remark that the coupling condition of eqn.(1), which in the photon theory expresses momentum conservation, becomes a simple classical condition of phase matching (Ref. [9], Chap.16) on cancellation of $\hbar$.

In Fig.2 we have denoted the zeropoint inputs by interrupted lines. All “photon detectors” (and this includes our own eyes) are blind to these modes; they register only when the intensity goes above zeropoint. (This is not strictly true, because there is always a residual dark rate, which the photon theory conveniently ignores. A realist theory of detection, such as ours [17], must include dark-rate detection events on the same footing as the detection of “signals”.) We have shown that the coupling process produces an intensity enhancement...
Figure 2: The field picture of PDC. All modes of the PDC rainbow are present, but as yet uncorrelated, in the vacuum. They become correlated as a result of the coupling inside the crystal (NLC). The coupling between modes is as in Fig.1. The pump mode is depleted, while the others are all enhanced.

in both the participating modes, and correspondingly a rather small depletion in the intensity of the pump, so this explains why there are counts in the two outgoing channels.

We have established that, within the experimental errors, the field description of all coincidence experiments, like Refs. [10, 11, 12], agrees with the photon description. But, in respect of the much simpler singles counting rate, there is a prediction made by the field theory for which the photon theory has offered no explanation. The rainbow shown schematically in Figs.1 and 2 does not contain all of the rays actually emitted by the crystal, because there is also a less intense satellite rainbow.

Let us look again at Fig.2 and ask the question “What happens if one of the incoming zeropoint modes, for example the lower 450\text{o}, is replaced by a laser, and the original laser, that is 300\text{e}, is removed?” Then the new pump is 450\text{o}, which produces no PDC rainbow, because the refractive index of the crystal, for frequencies below that of the pump, is less than the refractive index at 450\text{o}, so eqn(1) can not be satisfied. But the coupling which, in Fig.2, produced the outgoing pair consisting of the upper 450\text{o} and the lower 900\text{o} should, according to the field theory, still operate, because 300\text{e}, like all other modes, is present in the vacuum. This means that there are outgoing rays like those depicted in Fig.3. A detailed calculation[8] shows that, out of the three outgoing rays, that is (300\text{e}, 450\text{o}, 900\text{o}), the highest-frequency one is depleted while the other two are enhanced, which is exactly the same as when 300\text{e} was the pump, as in Fig.2. It may seem rather surprising that the process actually produces an enhancement, rather than a depletion, of the pump at 450\text{o}, but it was found that the changes in the intensities of the 300\text{e} and 900\text{o} modes are
Figure 3: Part of the PUC rainbow. A single set of interacting modes has been selected from Fig.2, and the roles of the input modes 300e and 450o have been reversed. As a result of the coupling the vacuum mode 300e is squeezed, while its partner 900o is enhanced, producing part of the satellite, or PUC rainbow.

only about 3 per cent of those in the main PDC process. Since, furthermore, these changes are in opposite directions, the pump enhancement produced by this process is extremely small compared with the depletion in the main process.

If the pump is in some polarization intermediate between e and o, then the main PDC rainbow will also be present, and then this second, weaker one will be observed as a satellite. As the pump's polarization plane is rotated, the relative strengths of the main PDC rainbow and its satellite will vary, the degree of extinction depending on the way the crystal is cut. I propose to call this satellite the Parametric Up Conversion (PUC) rainbow, because, although the only detectable mode of this rainbow coming out of the crystal (in Fig.3 the 900o mode) has a frequency $\omega$ which is less than the pump, its partner mode (the 300e mode) has the frequency $\omega_0 + \omega$. The PUC phenomenon is well established in classical nonlinear optics ([9], Chap.17), and my contribution arises from the recognition that this process must occur also from the vacuum. Of course, such a weak signal, at infrared wavelength, is not very easy to detect, but, subject to the refractive indices being such that eq.(1) has a solution, PUC may occur for any frequency less than $\omega_0$. For example if, for the pump, we use one of the incoming 600o modes of Fig.2, then an up converted signal at 600o will emerge from the crystal at an angle of 21 degrees to the pump. This up conversion results from the interaction of the pump with the two zeropoint modes (300e, 600o).
4 Conclusion

From 1905 to 1917 very few believed in photons, and it was Planck’s view, rather than Einstein’s, which commanded majority support. After Einstein’s famous article on stimulated and spontaneous emission the tide began to turn, and after the Compton effect the majority swung behind Einstein. Maybe the majority were right; we still have no theory of the emission of light by atoms which is consistent with Special Relativity, in the strict sense required by Einstein, Podolsky and Rosen[7], and therefore truly scientific in Einstein’s sense[1,2]. The history of science is full of cases when the majority continued to pay allegiance to a theory which they knew to be “absurd” (to paraphrase Ref.[6]), so let us hope that posterity will not judge them too harshly for making do with an unscientific theory for over 70 years!

Nevertheless, the above explanation of PDC, especially once its prediction of the new phenomenon has been confirmed1 should encourage us to try and do better in other areas of optics, and eventually of all atomic and subatomic physics.

I have reviewed elsewhere[19] how, in optics, nonlocal photon descriptions may be more or less systematically replaced by local descriptions which incorporate Planck’s field. This systematic replacement includes, indeed begins with, the celebrated experiments on Bell-inequality tests in atomic cascades[20], which was where “photon entanglement” was first observed. Most specialists, understandably, remained unimpressed, because, although our treatment of the field was unambiguously maxwellian, we had to improvise, in a rather crude manner, the description of the atom-field interaction. Nobody has yet succeeded in doing, for the Dirac field, what Planck did for the Maxwell field.

But when it came to PDC we did not need to know any details about the atom-field interaction; only the relation between the current and the field inside the crystal is relevant at optical and near ultraviolet frequencies. So a purely maxwellian theory, of the type I have outlined here, can engage with the theory depicted in Fig.1, and which I have called the Photon Theory, on equal terms.

Our alternative Field Theory is manifestly local and causal; the incoming fields generate a current in the crystal, and the outgoing fields are the retarded fields generated by those currents.

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