Excerpts from the original negative comments on the paper submitted by Popp and Nagl:

First referee: "The paper spends much of its text reviewing a viewpoint about low level coherence in biology which cannot possibly be correct. Particularly, coherent effects of the nature described have been (and are expected to be) observed only at very high intensities for absorbtion lines which are quite narrow. Since what is described is a broad-band phenomenon, coherence effects would necessitate colossal light levels while such effects are claimed for very low light levels. Non-exponential (inverse power law) optical decays are common in condensed matter, for a variety of well-known reasons, and the mere observation of nonexponential decay is totally insufficient reason to consider coherence as the cause.

The new material in the paper is chiefly an *ad hoc* theoretical analysis. The number of suppositions is very large, and the experiments do not bear on the theoretical analysis in a concise enough fashion to suggest any testable link between the analysis and the experiments."

Second referee: "The quoted experiments cannot be accepted as firm data. The authors do not specify the reproducibility of the data nor the experimental apparatus used."

"...The authors assume A and B independent of T and they use such an assumption in order to integrate equation 4. Later on, it seems that they forget the assumption, thus obtaining inconsistent results."

CONCERNING THE QUESTION OF COHERENCE IN BIOLOGICAL SYSTEMS

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Sometimes the idea that a very weak photonemission from living tissues ("low-level luminescence" (*1*)) exhibits an extraordinary high degree of coherence, meets rigorous objection because of the following arguments: (1) optical coherence could only occur at considerably high intensities, and (2) instead of a broad spectral distribution that is characteristic for low-level luminescence at least one narrow spectral line should be observed.

Both these objections obviously arise by considering the phenomena of technical laser physics, where in general one transition is pumped with considerably high power in order to overcompensate spontaneous decay. Of course, these arguments cannot be based on the more fundamental theory of optical coherence which has been developed, for instance, by R. J. Glauber (2) and for our particular case, also by E. Wolf (3).

Hence, according to this basic concept, a necessary and sufficient condition for coherence to nth order is the factorization of expressions like:

$$G^{(n,n)} = \mathrm{Tr}\{\varsigma \vec{E}_+(\vec{r_1}, t_1)\vec{E}_+(\vec{r_2}, t_2) \ldots \vec{E}_+(\vec{r_n}, t_n) E_-(\vec{r_n}, t_n) \ldots \ldots \vec{E}_-(\vec{r_2}, t_2)\vec{E}_-(\vec{r_n}, t_n)\} \tag{1}$$

where ς represents the density matrix of the field. The $\vec{E}_\pm(\vec{r_i}, t_i)$ are the mutually adjoint electric field-operators at space-time points $\vec{r_i}$, t_i. Reference (*1*) describes the probability that an ideal broad band photoabsorption counter registers photoabsorption by succession of times $t_1, t_2, \ldots, t_n$ at corresponding points $\vec{r_1}, \vec{r_2}, \ldots, \vec{r_n}$. Coherent states that are defined according to (2) as eigenstates of the annihilation operator a_k provide complete factorization of (*1*).

$$a_k / d_k > \; = d_k / d_k > \tag{2}$$

Evidently, coherence according to (*1*) and (2) do not show any dependence on either the amplitude of the field, or on its spectral distribution.

Nevertheless, from a classical point of view, coherence provides the condition:

$$\dot{n}\, t > 1 \tag{3}$$

where $\dot{n}$ and t represent the total photon intensity (number of photons/ unit of time) and the coherence time, respectively. This means that the coherence time has to amount to considerably high values for weak luminescence, much higher than observed in technical devices. This holds from a classical point of view, but not from a quantum physical one.

Nevertheless, sufficiently high values of the order of minutes or even hours occur in the case of low-level luminescence. For the latter, the following aspects have to be carefully considered:

1. The spectral distribution of low-level luminescence corresponds to that of a multimode laser at threshold, when the probabilities of induced emission and absorbance are the same for all the possible transitions between excited states (*4*).
2. Therefore, this characteristic distribution allows a high optical transparency. This again has been demonstrated for both the biological matter (*5*) as well as for the weak biological radiation itself (*6*), indicating in fact the high degree of coherence. In addition, that kind of distribution suffices for a stable state far away from thermal equilibrium.
3. Moreover, by considering the relaxation dynamics of an unstable quantum system (*7–9*), one finds that a fully coherent field is under ergodic conditions described by a hyperbolic decay function, whereas under the same conditions a chaotic field obeys an exponential decay-law (*10*).

Actually, hyperbolic decay has been discovered in living tissues and could even be correlated to cooperativity from a biological point of view (*4,11,12*).

In order to avoid further misunderstanding, it should be noted that this hyperbolic decay can be observed even by separating single spectral lines. The fact that it is sometimes also observed in condensed matter physics does not exclude its fundamental biological importance. It has been shown that hyperbolic decay never refers to random rescattering (*13*) and that it would be unphysical to describe it by superposition of exponential functions (*14*).

Finally it should be noticed that a relatively well-defined molecular mechanism has been suggested, which is consistent with the experimental facts of low-level luminescence and which can also explain the extraordinary high degree of coherence (*15*).

Recently, our point of view has been strongly confirmed also by H. Paul (*16*), who investigated coherence at low intensities very carefully. A permanently stabilized coherent field is possible by squeezing it in between bunching and antibunching. This means that it is possible only at very *low* intensities.

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