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Concluding remarks

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The multi-author review presented here clearly shows that biophoton research has come of age. This is demonstrated by the amount of research activity in various countries, by the organization of symposia and conferences on this topic, and by the increasing number of original articles and books recently published on bioluminescence and related fields[1–3, 6, 7, 9 10, 15, 16, 19, 20]. The stream of progress may have its source – as is often in science – in the association of two disciplines, in this case of biological questions with physical concepts, from the experimental level to the thermodynamic and quantum mechanical level. By that combination, many so far 'unlaid eggs' have become fertilized and have been enabled to develop into new theories and research strategies.

In the present concluding remarks I should like to concentrate on some new opportunities in the understanding of biological phenomena and some new perspectives. I would also like to appeal to more 'conservative' colleagues to realize that scientific progress depends on the acceptance of new results, new methods, and new theories, because 'there is simply no absolute truth, but only relative truths, theories which change with the accumulation of *new knowledge*'[5]. This is, actually, *old knowledge* for the theories of science and cognition.

There are still a large number of biological phenomena and events that cannot yet be adequately explained, or even simply described, such as cell differentiation and its regulation, morphogenesis, and evolution. Some of the unsolved, but central questions, are specified in the following. Let us first consider a phenomenon at the molecular level. The genome size varies among eukaryotic species within the range of 1 : 14.000. The minimum DNA content increases with the complexity of the organism in a given taxon, but organisms of very similar complexity often exhibit extremely different DNA amounts. It is now evident that the number of genes (as well as their function) is rather similar among organisms, and that up to 99.9 % of the genome represents non-coding, regulatory DNA[8, 11, 13]. But little is known about *how* this regulation may occur, so that some scientists neglect that mass of DNA as 'selfish' or 'junk' DNA. If we consider the level of the whole organism, the diversification of cells and organisms during ontogenesis (individual development) and phylogenesis (evolution) clearly represents a basic aspect of living matter. But how is the program of growth, differentiation, reproduction etc. controlled? And how does the ordered development come to be disturbed in some cells?

I think that not one modern scientist can believe that all of these ordered processes are just the result of random events. But all the regulators envisaged so far, such as proteins and hormones etc., require some regulator themselves to be produced or be effective. So, if we confine our studies to the physiological and biochemical levels, we shall not find an end, but only more open questions than before. The number of cell divisions that can be performed by a given cell type, and the life span of the members of a given species, are determined and limited in some way, while cancer cells are able to escape that control. What makes the difference between ordered development and chaotic growth? If we only knew this, the therapy of cancer and the construction of living cells from a few inorganic molecules would be an easy game. Or, *why* do organisms become more complex during evolution? Adaptation in the Darwinian sense is possible at any level of organization[17], and the evolution of novel morphologies always *precede* adaptation and selection, and is evidently an *intrinsic* property of matter in general[8, 12] (consider also the evolution of the universe and the chemical isotopes). Similarly, changes in chromatin structure precede changes in gene activity, and changes in DNA conformation precede changes in chromatin structure. Changes in membrane organization precede hormonal stimulation, and changes in gene activity precede changes in membrane organization. Physico-chemical oscillations precede neural oscillations, secretory oscillations, cell cycles, diurnal cycles, reproduction cycles, and even life cycles. Cooperative phenomena at the atomic level precede the cooperative behavior of cells during differentiation.

Thus, the time is ripe to break down the dichotomy between biology and physics[4]. The present review is an attempt in this direction. New techniques have been developed. The increasing complexity of organisms can be understood according to the laws of non-linear thermodynamics of open systems which are far away from equilibrium. The non-coding DNA may act as a photon store and coherent radiator, because of its enormous polymer size and its ability to form exciplexes. The resulting long-range electromagnetic waves and fields can be seen as the basis of self-organization, autocatalysis, mitosis and differentiation. The change from a coherent to a chaotic emission may be envisaged as the fundamental event in the progress from an ordered to a disturbed state. The photochemistry and low-level luminescence of biomolecules and cells may show us the way to an understanding of the regulation of biological systems.

Physicists see their task, in contrast to most biologists, in treating things simply, in order to understand complicated phenomena in a unified way, in terms of a few simple principles[18]. One of these principles may be found in coherence[14]. The present review on biophoton emission is surely an important step towards the understanding of life.

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