The Light of Life – Biophotonics

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Abstract: Practically all organisms emit light at a steady rate from a few photons per cell per day to several hundred photons per organism per second. The emission of biophotons, as they are called, is somewhat different from well-known cases of bioluminescence. Biophoton emission is universal to living organisms and is not associated with specific organelles. Such emission is strongly correlated with the cell cycle and other functional states of cells and organisms, and responds to many external stimuli or stresses. Biophotons include electromagnetic radiation from extremely low frequencies - well below the visible range - and extend all the way up through microwave and radio frequencies on the other end of the spectrum. Contrary to the common assumption that molecular reactivity is determined by chaotic stimulation of thermal energy, it is the result of a spatio-temporal manifestation of electromagnetic field energy. The coherent property of this biophotonic field is thus an ability, a communicative tool without which the state of each cell both in single cellular as well as multicellular organisms could not be communicated to its surrounding. Coherence in this sense includes also communication processes that are not limited to the immediate proximity, but involves the entire organism. Even the DNA molecule is an excited duplex, or exciplex, in which photons are effectively stored. Biophotons are thus a key tool in inter- and trans-cellular communication processes. Rather than the "struggle for existence" do all organisms contribute in play-like fashion to a truly dynamic interplay of communicative interaction. Hence biophotonic processes along with intra- and inter-specific cooperation are essential features for life to occur in an orderly manner. Any outside interference – including physical and/or chemical disturbances – easily hampers these subtle biophotonic communication patterns and results in erratic messages and eventually in the manifestation of diseases.

Keywords: biophotons, bioluminescence, electro-magnetic radiation, microwave

1. Introduction

Light and matter are intimately linked. Indeed light and living matter have such a special relationship that it pushes at the very frontiers of current research in quantum optics and other nonlinear optical phenomena in condensed matter physics.[1]

Historically, this phenomenon dates back to *Gurwitsch*'s famous onion experiment.[2, 3] Whereby, he perpendicularly positioned the roots of two onions so that the tip of one root points to one side of the other root. *Gurwitsch* found that there was a significant increase in cell divisions on this side, compared to the opposite, "un-irradiated" side. The effect disappeared when a thin piece of window glass, which is opaque for ultraviolet light, was placed between the two roots.

The word "biophoton" has been chosen to express the fact that the phenomenon is characterized by measuring single photons, indicating that it has to be considered as a subject of quantum optics rather than of "classical" physics. Biophoton emission is a general phenomenon of living systems. Practically all organisms emit light at a steady rate from a few photons per cell per day to several 100 photons per organisms per second and square centimeter surface area, within the spectral region of at least 200 to 800 nm. Biophotons are associated to energy-matter interactions; i.e.: absorbed electromagnetic radiation (EMR) results in an excited atomic state (quantum jumps) and vice versa. In order to establish trans-molecular communication, the molecules involved must be in some kind of excited state.[4] Classical observations in solid state systems suggest that relaxation can occur in definite quantum steps, i.e. the electron may fall to a lower yet still excited state without the emission of visible light, or may start to move, thus becoming an electric current, or yet in other cases it can be involved in a chemical reaction. Complete relaxation to the ground state - recombination with the positively charged hole left behind - would result in the emission of EMR. Yet it is known from quantum electrodynamics, that orbital electrons and the nucleus are constantly exchanging virtual (not quite real) photons. However, in biotic systems an excited electron-hole pair, or exciton, can propagate over long distances within the system before releasing the energy by emitting a photon. It is believed that the formation of excitons and their propagation are involved in major energy transductions and in bio-communication. In fact, the DNA molecule itself is considered to be an excited duplex, or exciplex in which photons are effectively stored between the two DNA strands. Hence, living systems emit light from processes taking place all over the cell.[1, 5]

As living systems are reciprocally coupled entities embedded in an appropriate environment, this coupling process results in coherent interactions with all cells that constitute an organism. As biophotonic activity is strongly correlated with the cell cycle and other functional states of cells and organisms, coherence when biophotonically monitored, can be tapped via a hyperbolic decay pattern that is independent of the emitted wavelength. This is in sharp contrast to "incoherent systems" that follow an exponential pattern, as is the case in radioactive decay.[1]

However, in order to detect biophotonic activity, one has to irradiate the sample with white light.[1, 5]

2. Biophotons and Semiosis

2a. Biophotonics and the DNA

In-situ, at least 75% of biophotonic activity originates from the DNA. However, when isolated and purified, DNA is biophotonically inactive. DNA possesses an information density that is $1 \cdot 10^9$ higher than any technical solution known today. Spread out, this macromolecule stretches out to 2 m in length in which $100 \cdot 10^9$ base-pairs are sophistically wrapped. Taken all the DNA of a human and lining them up, it would cover a distance of $10 \cdot 10^{12}$ m, which is more than the diameter of our solar system.[6] This exorbitant information density leads to a phenomena known in physics as *Bose-Einstein*-Condensate (BEC); that is, photons are trapped, much like in a cryotrap, condense and "freeze" in time. The stored light accounts for the elemental stability of the DNA-molecule. It is thereby assumed that the 97.98% of inactive human DNA along with the "frozen" energy has the essential role of organizing the 2.02% of genetically expressed DNA. Hence, the BEC establishes a coherent cell-biological state in which photons of same frequency and phase align to each other. Thereby, the range of interaction increases from the microscopic to include macroscopic entities to involve cells, organs, and entire organisms and even beyond.[5]

The BCE plays an essential part in the formation of the morpho-genetic field (MGF). It is basically a chemico-mechanico-electric field that exerts its action in the nanometer range. It induces a holistic action onto the DNA thereby controlling growth, differentiation and coordination. It is capable to deform larger molecules by altering electric fields and chemical potentials only to feed back onto the molecular behavior. In turn, weakening this field induces chaotic morphogenesis: i.e. if the MGF is not in an equilibrated state, these structures oscillate over a large bandwidth. Experiments made with *Drosophila* embryos exposed to weak electrical and magnetic fields have shown that they interact with the MGF and induce malformations, which result in missing extremities, twisted body axis, or even phenotypic expression of ancestral traits that are already extinct.[1] Hence, biophotonic emission patterns are directly linked to the MGF and show definite emission patterns.

2b. Biophotonics and the Cell

Biophotonic activity within a cell can be easily monitored during mitosis. Detailed observation of mitosis has shown that there is good agreement between the structural pattern of the spindle apparatus and electrical field lines. In any moment of this process the interior of the cell reveals a spatial energy distribution that controls the release of chemical reactions in a well-coordinated functional sequence. As a result it was suggested to compare mitosis with a technical cavity resonator. Doing so, one obtains evidence that mitotic patterns are excellent examples of long-lasting photon storage units in biological systems.[5, 7]

As with solid-state systems, superposition of different modes in the optical range of EMR yield a spatially fine resolved intensity-pattern of "standing waves". The spatially distributed electric field serves as a guiding force for molecules and accurately trigger more than $100 \cdot 10^3$ chemical reactions per second. The cytoplasm, on the other hand, provides only a fraction of the biophotonic activity.[4] However, the microtubules of the cytoplasm plays a vital role in the propagation of the biophotonic emissions originating from the cell nucleus, and along with tight-, adhering-, and communications junctions they conduct biophotonic pulses to neighboring cells and to the extra-cellular matrix. Adhesive forces between cells connect them to functional units and thus form a resonator system also for long-wave photons. When a cell of such a unit dies, the resonance-frequency is disturbed, and results in the emission of some photons, thereby initiating the process of cell regeneration.[5]

Quorum sensing, is a well-studied example of communication-based cooperation among single-celled organisms – such as colonial bacteria.[8] A very stark example of this capability can be observed in *Paenibacillus vortex*. As the name suggests, its advanced sensing faculties are so elaborated that it is capable to form structured colonies in which task separation is performed. Part of the colony forms a condensed group and eventually will evolve a vortex and swarm collectively around their common center at about 1 μm/sec. Ongoing communication on the colony level is particularly apparent when it comes to the birth of new vortices.[9, 10]

An even more striking example of direct intercommunications can be found between separate populations of the luminescent dinoflagellate *Gonyaulax polyedra*. Two identical quartz cuvettes, filled with the same population density from the very same culture, are found to synchronize their light flashing when they are in optical contact but detune when separated by an opaque barrier.[1, 5]

2c. Biophotonics and the Organ

The purpose and function of biophotons also regard the superposition from various cells within an organ. Here, cell-membranes are positioned in the nodal planes of interference patterns. As can be observed with the cell-cycle, the energy distribution of the extracellular space serves as communication means and to interact with regulatory process within neighboring cell-units. In this regard the connective tissue (CT) with its network of collagen fibers plays a crucial role. The conventional view assigns the CT a mere bonding role that ties tissues together and supports flexible body parts. In biophotonics, however, the CT is given a more fundamental role as it represents the "fiber-optical" network that conducts optic messages throughout the body.[1]

Another examples in which biophotons play a crucial role are molecular signal cascades. It is common to all processes involved in signal transduction and is used to amplify extremely weak stimuli. The nervous system of the retina for example, has time constants, which are in the order of $10 \cdot 10^2$ sec - far too slow to account for the rapidity of visual perception. Thus it would take about 10 msec to activate one molecule of phospho-di-esterase after photon absorption. Much of the amplification is actually in the initial step, where the single-photon-excited rhodopsin passes on the excitation to at least 500 molecules of transducin within 1 ms. Although the underlying mechanism is still subject of current research it is assumed that biophotonic processes are involved.[1, 5]

A yet different example of how biophotonics is embedded in the macroscopic framework can be found in muscle fibers. The energy stored in a single molecule is released in a specific molecular form and then converted into another specific form so quickly that it never has time to become heat. Macroscopic action is produced by the sum of all the individual molecules involved – predominantly myosin and actin. These molecules are packed and arranged very precisely, approaching the regularity of piezo-crystals, causing even muscles to emit biophotons. Since muscle contraction involves electron tunneling (going under an energy barrier that occur within nanoseconds), the fluctuations have to be coordinated in order to do useful work. Hence, stored energy capable of doing work must be coherent energy. Furthermore, muscle contraction along a single fiber occurs in definite and synchronous quantal steps. The catenated process - here the sliding actin-myosin filaments - is essentially fluctuationless and is a characteristic of a coherent quantum field. The astronomical number of cells involved in a typical muscle contraction is executing the same molecular threadmilling in coherent manner - just as in a concert. However, it does so over a scale of distances spanning nine orders of magnitude. In addition skeletal muscles contraction is sustained over a long period without break. Here energy is available to us at will in the amount we need at almost 100% efficiency.[1, 5]

Further evidence of coherence on a higher level can be found in chronobiology. It is a field of science that examines cyclic phenomena in living organisms and include many essential biological processes – in animals: eating, sleeping, mating, hibernating, migration, cellular regeneration, etc.; in plants: leaf movements, photosynthetic reactions, etc. The most important rhythms in chronobiology are the circadian rhythm, migration and reproduction cycles, rapid-eye-movement cycles, tidal cycles, etc.

2d. Biophotonics among Species

Coupled biological rhythms and synchronization in conventional biology can be found among shoals of fish or even swarms of birds. Such aggregations consisting of up to several thousand individual specimens move effortlessly, spontaneously and freely in unison without following marching orders from a leader. Yet it appears that the coordinating principle causes each individual to receive signals for enhanced coordinated action. In order to maintain coherence, these signals must arrive there long before they actually become manifest as coordinated motion.[1] Only then can synchronicity be achieved within the entire population. This suggests that there is an underlying system of communication that sends messages simultaneously to all organs, including those perhaps not directly connected to a signaling (e.g. neuronal) network; i.e. it could be associated to some kind of entanglement – a concept already well elaborated in solid state physics. Thus, coherence too, refers to wholeness and relates to a healthy steady state. This pure state - not to be confused with a mixture of states – enforces the existence of biological rhythms as such.

Common examples of such coupling mechanisms regard the harmonic relationships of respiratory and heart-beat frequencies. Another case is found in the oscillating wave of beating cilia of deep-ocean ctenophores or even in mucus transportation by bronchial cilia in lungs of mamals. A well-studied example regards the genes in *Drosophila*; they reveal chronobiological coupling relationships over 7 orders of magnitudes of time periods linking the circadian to the wing beat rhythm of the male fly's love-song. Indeed, many organisms, tissues, and cells show spontaneous oscillatory contractile activities that are coherent over large spatial domains with periods ranging from milliseconds to minutes.[1]

Once the natural state of coherence is established, synchronization is eventually expredded on an even a larger scale. It is known from physics that any population of oscillators interact with every other via the absorption of oscillating energy, thus resulting in phase locking (PL). Such principles are technically applied in PL-locked electronic circuits of wireless communication devices. Examples of synchronously oscillating and PL-locked biological systems include populations of fireflies that flash together in unison, coral spawning, synchronized crickets chirping, among sardine baits, swarming birds and so forth. These phenomena are even found in the pacemaker cells of the heart, the neuronal network of the circadian clock of the hippocampus, and the insulin-secreting cells of the pancreas. Likewise, the movement of the limbs bears a definite phase relationship to one another that are simultaneously reflected in the electrical activities of the corresponding motor center in the brain.[1]

Chronobiological investigations among higher organisms, as for example in teacher-student interactions revealed that periods of stress on the teacher's side negatively feed back onto the concentration efficiency of the pupils in class.[11] Such correlations can also be found in patients suffering from chronic diseases. The more severe the disease, the less the patient is able to respond with an appropriate regulatory process. Coma patients, for instance, are found to have such restricted regulatory patterns that failure of one of them results in immediate death. On the other hand, relaxed people have numerous regulatory patterns to choose from when exposed to internal or external stress factors.[12]

3. Beyond Biophotonics

A coherent state thus maximizes both global cohesion and local freedom. Nature presents us with a deep riddle that compels us to accommodate seemingly polar opposites: deterministic and probabilistic properties at the same time. However, coherence does not mean uniformity. One can begin to understand it by thinking of an orchestra, where every member is performing his or her part, and yet stay perfectly in tune with the rest. In such an imaginative super-orchestra, coherence both within each member as well as beyond includes the entire group. It must span an incredible spectrum of sizes, from nanometers all the way up to the macroscopic range, covering a spectrum of at least 72 octaves.[1] Without destabilizing the whole, each and every player, however small, can enjoy maximum freedom of expression while at the same time contributing to a harmonious performance.[16] One can imagine what happens if just a few members of the orchestra decoherence by playing the wrong tune: it disturbs the harmony of the entire orchestra, or to put it in *Bohm*'s terminology: it interferes with the explicate order.[13] Here, the key issues are correlations between observables of entities which seem separated by great distances in the explicate order, but are nonetheless governed by manifestations of the implicate order. This idea is rooted in the concepts of quantum theory, where entanglement is an accepted fact, and living beings are quantum beings. This view of order necessarily departs from a notion, which entails signaling, and therefore causality. The correlation of observables does not imply a causal influence, and represents 'relatively' independent events in space-time; and therefore is the explicate order of our so-called "reality". Thereby, unfoldment characterizes processes in which the explicate order becomes relevant or "relevated".[13] Patterns of interaction within the continuum of both implicate and explicate orders are basically the same in all organisms, and includes intra-, inter, and meta-communication. No organism can exclude itself from these communication patterns at any stage in its lifespan. Fruitful interdisciplinary cooperation between socio-biology and semiotics is evident in sign-mediated communication processes. These processes are used in any individual to coordinate behavior and to enter in associations that are essential for the survival and prosperity of all species. Even though the "language" used is quite different in all of the known taxonomic kingdoms (bacteria, protista, fungi, plantae, animalia), all of them rely on:[7, 14]

1) syntax, which refers to formal correctness, i.e.: in linguistics it is the grammar;
2) semantics, which refers to the significance and how it is used, i.e.: in linguistics it is synonymous for the interpretation in order to create a meaningful context; and
3) pragmatics, which refers to the aim or the effect of the message conveyed, i.e.: in linguistics it regards that provoke feelings and reactions.

4. Conclusion

Evaluating the phenomenon of biophotons, it becomes obvious that nature has not designed organisms following some pre-designed blueprint, but rather via a process of biotic self-organization that is embedded within the MGF. Organisms do not store the information required to construct the system, but rather the information for creating the needed "tools" and the guiding principles. Additional information is cooperatively generated as the organization proceeds following external stimulation. The outcome is an adaptable complex system, capable to evolve, that can perform many tasks, learn and change itself accordingly. These features are biophotonically mediated and regard the following regulatory processes:

- spatially inhomogeneous energy distribution structures biological matter;
- biological matter changes the spatial distribution of energy;
- feedback-loops exhibit a self-organizing control of the regulation process;
- regulation processes enable growth and lead to an increase in functional complexity.

Doing so, three distinct conditions need to be fulfilled. First of all, the bio-communicative means have to obey syntactic rules, a grammatical structure to comply with formal correctness. In order to be interpreted in a meaningful context, these messages have to bear semantics. And finally the associated pragmatic aspect that gives the message a value, which provokes certain reactions.[14, 15]

Collectively, even the simplest forms of life, such as bacteria, reorganize themselves by gleaning relevant latent information embedded in the complex environment and pave the way for the evolutionary path that gives rise to other and even higher organisms. Bacteria interpret the information in an existential (meaningful) way, develop common knowledge, and learn from past experience. They do so by acting coherently as a whole.

Coherence is the capability of each unit to interact with all the other parts that constitute a living system. It is possible to show evidence of an extraordinary high degree of coherence of biophotons. It follows that this universal phenomenon of biological systems is responsible for the information transfer within and between cells, organs, and organisms. This responsive pattern is crucial for intra- and extracellular bio-communication, including the regulation of the metabolic activities of cells as well as of growth and differentiation and even of evolutionary development. Organisms are neither mere subjects, nor objects, but subjects and objects at the same time. In contrast to the Neo-*Darwin*istic point of view, the capacity of evolutionary development does not originally depend on the rivalry and power in the fight for existence, rather, it depends mainly on the capacity of communication in which the relationship attains a far more important function than the biological entities themselves. Living systems are dynamic, multimode storage structures that communicate in various ways, which are rooted in biophotonic action. This contributes to a totally new dimension in the preservation of biodiversity, and the embedded principle of self-organization. It is a process where the organization (constraint, redundancy) of a system spontaneously increases and is controlled by the environment or an encompassing or otherwise external system. Not only cellular compounds and population of species but also growth, embryogenesis, morphogenisis, biological rhythms, metamorphosis, differentiation of tissues, as well as communication and social forms, patterns and behaviors of individuals and populations are organized and regulated by coherent photons.[5, 15] Coherence is strongly correlated to biological rhythms and extends over some ten orders of magnitude - from millisecond oscillations of membrane action potentials to circa-annual rhythms of entire populations. It seems obvious that theses oscillations must be coherent over varying spatial domains that again stretch from single cells to entire organs, organisms and to populations of organisms that form the network of life.

The implications of such correlations uncover a vast unexplored area, whereby the notion of nonlinear, structured time represents itself as far more common than previously considered in the conventional scientific framework.[1]

References:

1. Ho MW (2003). The Rainbow and the Worm: The Physics of Organisms; 2nd ed.; World Scientific, Singapore.
2. Gurwitsch AG (1926). Das Problem der Zellteilung, physiologisch betrachtet; Protoplasma 1/1: 473-475.
3. Klimek W (2005). Biophotonics - A Review. Int. Institute of Biophysics, Neuss.
4. VanWijk R (2001). Bio-photons and Bio-communication; Journal of Scientific Exploration: 15/2.
5. Bischof M. (1995). Biophotonen, das Licht in unseren Zellen. 2001-Verlag. Frankfurt / Main.
6. Popp FA (2002). Die Botschaft der Nahrung. 2001-Verlag. Frankfurt / Main.
7. Dürr HP, Popp FA, Schommers W (2000). Elemente des Lebens. Alfred Schmid-Stiftung, Zug.
8. Bassler BL (2001). Tiny Conspiracies: Cell-to-cell Communication allows Bacteria to coordinate their Activity. Natural History Magazine: 110/4.
9. Ben-Jakob E (2003). Bio-Inspired Engineered Self-Organization. Online: http://online.itp.ucsb.edu/online/pattern_c03/benjacob/
10. Ben-Jakob E, Shapira Y, Tauber AI (2006); Seeking the Foundations of Cognition in Bacteria: From Schrödinger's Negatice Entropy to Latent Information. Physica A 359: 495-524.
11. Balzer HU (2004). Auswertung des Beanspruchungsverhaltens (Konzentrationsphasen und Wechselwirkungen) im Verlaufe eines Schulunterrichts zwischen einer Lehrerin und Schülern. Unpublished.
12. Hecht K, Balzer HU (1999). Psychobiologisch-regulatorische Aspekte der Stressdiagnostik als Evaluierungsmethodik wissenschaftlicher Arbeitsprojekte. in: Dauer S., Hennig, H. (Hrsg.). Arbeitslosigkeit und Gesundheit: Beiträge zur Medizinischen Psychologie und Grenzgebiete (Bd. 1): 145-166.
13. Bohm D (2004). Wholeness and the Implicate Order. Taylor & Francis, London.
14. Witzany G (2005). The *Logos* of the *Bios* 1. Umweb, Helsinki.
15. Kratky WW (2003). Komplementäre Medizinsysteme. Ibera, EUP.
16. Berendt JE (1985). Das Dritte Ohr – Vom Hören der Welt. Rowohlt, Hamburg.