# Introduction

## The role of bioelectromagnetic and photobiological factors in functional and structural organization of biosystems – Towards a new paradigm in the understanding of life

In recent years, an increasing number of results from basic research support the view that biophysical, in particular *bioelectromagnetic* and *photobiological* factors are fundamental for the functional and structural organization of biosystems. Despite the relatively well-known and well-researched bioelectromagnetic factors (endogenous currents, static and dynamic electric and magnetic fields as well as electromagnetic fields) in the context of biological function, photobiological factors (endogenous photon emissions) have become the focus of research as an additional entity influencing and guiding life processes. Are we heading towards a new paradigm in the understanding of life?

On the one hand, photobiological factors can be regarded as a subclass of bioelectromagnetic factors since light or a photon is a specific type of electromagnetic field (i.e. in the range from the lower part of the ultraviolet spectrum [UV, approx. 10 nm] to the upper part of the infrared spectrum [IR, approx. 1 mm]). On the other hand, the distinction between bioelectromagnetic and photobiological factors is justified because of the need to use different physical frameworks for their description, i.e. classical electro-dynamics and quantum physics, respectively.

Whereas traditionally *biochemistry* is regarded as the basis for both *intrasystemic* (within a biosystem) and *intersystemic* (between biosystems) organization, many facts support the notion that *biophysics* plays a significant role as well. The research activities regarding this aspect can be categorized into four classes (see Table 1). The categorization is based on the insight that the inter- and intrasystemic organization of a biosystem (i.e. a cell or a whole multicellular organism) or a collective of biosystems, respectively, stand also strongly under the influences of bioelectromagnetic and/or photobiological factors.

The research fields that investigate the bioelectromagnetic and photobiological processes involved in the intra- and intersystemic organization are *bioelectromagnetics* and *photobiology*, respectively. It should be noted that both research fields traditionally focus mainly on how *exogenous* electromagnetic or photonic factors can have an impact on biosystems while they include also research on *endogenous* (i.e. within a biosystem) electromagnetic or photonic factors. In the present book we mainly focus on *endogenous* bioelectromagnetic and photobiological processes.

| | Intrasystemic | Intersystemic |
|---|---|---|
| **Bioelectromagnetics** | Dielectrophoretic forces or electric signalling within a cell | Electric signalling between cells |
| *Prominent researchers in the field of bioelectromagnetics are for example: H.S. Burr, R.O. Becker, B. Nordenström, M. Levin, R.H. Funk, L.F. Jaffe, K.B. Hotary, R.B. Borgens, J. Pokorny, M. Cifra, J. Tuszynski* | | |
| **Photobiology** | Photonic signalling between fluorophores in a cell | Photonic signalling between cells |
| *Prominent researchers in the field of photobiology are for example: A.G. Gurwitsch, V.P. Kaznacheev, G. Albrecht-Bühler, D. Fels, F.A. Popp, R. Van Wijk, E.P. Van Wijk* | | |

**Table 1.** Categorization of four research sub-fields involved in the understanding of bioelectromagnetic and photobiological processes of intrasystemic and intersystemic organization of biosystems. Note that only examples of research topics are given in the research sub-fields.

While the role of bioelectromagnetic factors in the organization of biosystems is a well-established field of research, the understanding of photobiological factors involved in life processes is still at the beginning and has the potential of a very important topic for future biophysical research. To understand the significance of photobiological factors with regard to biosystems, let us first draw our attention to the role of light in the biosphere.

Light ranging from 200–1000 nm (i.e. the UV, visible and near IR range) comes from the biggest local energy source we can have access to, the Sun. While these higher frequencies are shining on Earth, only the lower IR frequencies leave the Planet, radiating back to Space. Part of the energy is absorbed by the exposed surface of the geosphere and another part is absorbed by the biosphere. What happens with the light that Life uses? Organisms with light receptors can use the light (also when reflected from surfaces) as a signal and organize themselves in accordance to their needs: e.g., for growth, phototaxis, attack, escape or mating. In fact, a great deal of the dynamics of ecosystems is based on photosynthesis and vision. Hence, light plays not only a decisive role as energy deliverer for the biosphere and its ecosystems but also a fundamental role in the way these systems are functionally organized. We know this. And yet, we would like to lead the reader into the cell(s), asking whether the ”cellular ecosystem“ is also (at least partly) organized by light or fields, respectively.

Let's step back. We know what happens with sunlight in the kingdom of the plants: photosynthesis transforms electromagnetic energy into energy of excited electrons, the latter being captured in sugar molecules ($C_6H_{12}O_6$) that form from carbon dioxide ($CO_2$) and water ($H_2O$) with the associated release of oxygen ($O_2$). These sugar molecules (i) are stored immediately (as starch) or (ii) used as raw material for producing (together with, e.g. phosphate and nitrogen) other organic molecules such as lipids, amino acids or more complex molecules such as, e.g., porphyrines or DNA, or (iii) they go directly into a chemical pathway that kind of inverts photosynthesis: glycolysis and mitochondrial respiration.

In both plant and animal cells, glycolysis and mitochondrial respiration serve to gain back the electromagnetic energy stored not only in (the binding electrons of) sugar but also in all the molecules built. This process is finalized in the mitochondria when protons ($H^+$) and electrons ($e^-$) as well as carbon dioxide ($CO_2$) get separated from the molecules. In the respiratory chain of the inner mitochondrial membrane the electronic energy is used for pumping the protons into the intermembrane space leading to extremely high concentrations of positively charged protons. This will cause two phenomena. One is the flow (along an electric and concentration gradient, respectively) of these protons back into the matrix – along ATPase – where they combine together with the electrons and $O_2$ to $H_2O$ while adenosine diphosphate (ADP) + phosphate ($PO_4^-$) are catalyzed to adenosine triphosphate (ATP). ATP is then used as a source of activation energy in many kinds of processes involving muscular and neuronal activity as well as molecule synthesis where some of its energy goes into these processes. However, some of its energy goes also into the environment as (low) thermal energy contributing to the thermal bath of the cytoplasm. Yet, the other phenomenon is that a tremendous electrostatic potential builds up between the (hundreds and more of) mitochondria per cell and their surrounding cytoplasm.

We could stop there, claiming that this is all we can say about the energy delivery: it comes from ATP and the thermal bath, which latter contributes to the chances of collision of reaction partners. But when biomolecules are fed into the mitochondria oxygen is not only used for water formation, it is also used in redox reactions and is involved in the production of so called reactive oxygen species (ROS). What is interesting here is that reactions of ROS and following products lead to the release of photons in the visible range. Can these photons have effects in the cell, delivering activation energy or functioning as a signal inducing particular chemical reactions, or are they just an insignificant byproduct?

Moreover, the tremendous $H^+$ concentrations in the mitochondrial intermembrane space organize charged molecules due to their high electric potential. Charged atoms, i.e. ions in general, play an important role regarding life processes. They build electric fields used for signal transduction in the nervous system, they organize space in the context of morphogenesis, induce gene expression and they are used for osmosis, the water content regulation of cells. Surprisingly, latest studies in water research point out that water itself can build electric fields. If we recall that charged particles cannot remain inert in an electric field and that molecules show to great extent dipolar functional groups, it is a small step to imagine or rather conclude that the fields of the cells organize the structure of the cells. Research on the impact of magnetic fields on life organization finds evidence for ferromagnetic particles and magnetosensitive chemical reactions in bacteria or birds, enabling these organisms to respond to the structure of the earth magnetic field. We can envision that the fields of the cells give structure, hence playing an important role in the process of self-organization (Fig. 1).

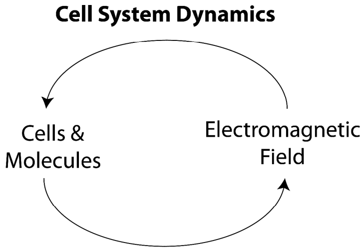


**Figure 1.** Illustration of the major hypothesis of this book, namely that charged cells and molecules, respectively, induce electromagnetic fields that feed back on these cells and molecules where both the charged parts and the fields together build a system of causal reciprocity leading to observed cell system dynamics.

The goal of the present book is to introduce the role of endogenous biological electromagnetic and photonic factors influencing and guiding life processes. To this end, we invited experts in these research fields to write a review summarizing the research findings they gathered over many years. Each review obtained is one chapter of the present book.

The first chapter introduces the history of the field concept in biology from the early 20$^{th}$ century to recent times covering all important milestones and related theories on non-equilibrium, non-linear and coherent behavior of biological systems. The second chapter explains the physical view on the electromagnetic field and photons. The electromagnetic spectrum is described as well as coherence, interference, resonance and interactions of an electromagnetic field with matter. Chapter three then gives an overview of detection techniques for ultraweak photon emission, such as observed from biological systems. Chapter four describes fundamental features of living system that are nonlinear and far from thermodynamic equilibrium: a rise of order from disorder. This is possible for cases where energy is flowing through the system and the system is able to dissipate the disorder (entropy) to its surroundings. Doing so, internal ordering of the system is achieved. In chapter five we come across experimental findings about water behavior indicating that water at hydrophilic interfaces is the simplest non-equilibrium system able to transform disordered to ordered energy. Hence, a theory of coherent water domains will be presented, explaining both, well-known and newly observed properties of water. It is concluded that water plays a central role in the dynamics of biomolecules and therefore also subsequently in the generation of the cellular electrodynamic field.

One of the manifestations of living system's non-equilibrium behavior is the permanent production of electron excitation in biomolecules leading to ultra-weak photon emission. Based on solid experimental evidence, chapter six explains the generation of electron excited chemical species due to free radical and reactive oxygen species reactions. Biological ultra-weak photon emission is of very general nature. It is detectable from every metabolically active biological species under suitable conditions. Chapter seven focuses on ultraweak photon emission from multicellular organisms, namely plants, tumor tissues and humans. It relates photon emission to development and structure as well as to tumor and normal cells comparing them with reference to growth properties. The eighth chapter explains the peculiar phenomenon of non-chemical influences between cell cultures through glass barriers. It is suspected that the non-chemical interaction between cell cultures is mediated by photon emission generated by cells. A special emphasis is given on confounding effects and the method itself in order to gain understanding about the function. As statistical properties of biological ultra-weak photon emission have been a source of controversy in past decades; chapter nine assesses available experiments studying optical coherence, quantum states and signal properties of biological ultra-weak photon emission. Chapter ten aims to explain that the electrodynamic activity of living cells involves a broad range of frequencies, namely from kilohertz to terahertz. These frequency ranges are related to electromechanical vibrations of subcellular structures. It is hypothesized that electrodynamic fields generated by such sub-cellular coupled oscillations contribute significantly to biological self-organization.

Can biomolecules interact over long distances within a cell in order to *find* their chemical partners earlier than just by diffusion? Chapter eleven explains under which conditions such interactions can indeed take place using a model that involves resonant electrodynamic interactions of biomolecules. Rising to a macroscopic level, we come in chapter twelve across the collective activity of neurons giving rise to synchronous electric events in the brain. Such events are also known as preconditions for conscious acts to occur. Both, the potential role of photons emitted from neurons and being part of a time-sensitive signal flow within the brain (and the body) as well as synchronicity between distant brains are discussed with care. Coming down again to the microscopic world, the organization and signal processing on the level of single eukaryotic cell and especially neurons is crucially dependent on the cytoskeleton. In chapter thirteen the electric properties of microtubule and actin filaments are described as well as their possible role in cell signaling. Chapter fourteen then guides us from early biological field concepts to a modern theory of biological self-organization involving the coupling of fields from mechanic, electric and electromagnetic origin. Chapter fifteen provides us with condensed information on how tissue and cellular electric fields modulate the transcription of genes and shows, thus, basic principles of how cellular electric fields are coupled with biochemical pathways. The final chapter introduces the fact that biological objects, as any other dielectric objects, are able to store electromagnetic energy as cavity resonators under certain conditions. In resonators, electromagnetic energy is stored only in certain shapes (modes) at a certain frequency. Here it is proposed, that the spatial distribution of electromagnetic energy in such biological resonator provides conditions for symmetry breaking which guides differentiation and pattern formation during plant organ development.

As every research field needs some critical amount of knowledge to be gathered until it can start to expand rapidly and bring applications, we wish the reader to be well-introduced and motivated starting his or her own research projects.

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