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Bio-photons and Bio-communication[1]

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Abstract—The topic of bio-informational aspects of photon emission has a history of more than eighty years. It is an example of a research topic that is inadequately studied within mainstream biology. This article reviews the research activities during the three main phases of this line of this research. The first period is characterized by Gurwitsch-type experimentation on mitogenetic radiation. Radiation was detected by changes in biological organisms that function as radiation detectors. The second phase is characterized by the development and application of sensitive photomultiplier tubes for the detection of radiation from organisms and cells. These studies were extended with the question about the chemical and enzymatic origin of radiation. In this phase hardly any attention was paid to the question of radiation with a bio-informational character. In the third period research is again focussed on the informational aspects of photon emission. This bio-photon research is hardly recognized in mainstream science so far, but in the opinion of the author it deserves careful consideration. For this reason this article presents an overview of the literature which might be helpful for giving careful consideration to the bio-informational character of bio-photons.

Keywords: bio-photons — chemiluminescence — communication — mitogenetic radiation

Introduction

The research on bio-informational aspects of bio-photons in the IR to UV range can be traced back to Alexander G. Gurwitsch more than seventy years ago. He emphasized that fundamental biological functions such as cell division are triggered by a very weak ultraviolet photo-current originating from the cells themselves.

This postulate of bio-photonic information appears to many scientists to be pure speculation, and it provokes sometimes contempt rather than carefully considered objections. This article reviews the activities of research groups on three different main questions concerning this bio-photonic information.

The first question deals with the developments in the evidence for photons originating from cells. Despite serious experimental difficulties it is now clear to every scientist working in this field that photon emission could be detected from nearly all living cells.

The second question considers the origin of photon emission. Very weak photon emission has been looked upon so far mainly from the possible reactions and biochemical pathway that could be responsible for this phenomenon. In general, those studies were carried out without considering Gurwitsch's idea of bio-information of photon emission. An alternative search for the origin of photon emission has been carried out incorporating the informational aspect of photon emission. This type of explanation proposes the existence of a coherent electromagnetic field within cell populations and has led to the introduction of the term bio-photons. Bio-photons are characterized by their quantum character and are supposed to escape from a coherent field. This alternative explanation is supported by several arguments.

The third question is the most decisive one from an empirical point of view. It is directed to the existence of bio-photon emission in relation with cellular interactions and biological function. In general the idea that beside, or even below, the biochemical level of control very weak electromagnetic interactions play a regulatory role in the living state has received relatively little attention. The present research has not yet reached the state required for the ultimate verification or falsification of the hypothesis on bio-photonic information in cell division and other cell physiological processes, as originally investigated and suggested by Gurwitsch.

The Origin of Mitogenetic Rays

The mystery of the sporadic arising of cell divisions was the starting point for Gurwitsch to carry out his famous "mitogenetic radiation" experiments in 1923. The idea that radiation generates cell division was based on his early studies (Gurwitsch, 1911) in which it was demonstrated that (1) there is a reverse linear relationship between the surface areas of the meristemic cells and their division frequencies; (2) along the whole onion root meristem, cell surface areas increase according to the exponential law. The purely statistical character of spatial distribution of mitosis demonstrated in several objects (and particularly in onion roots) supported the concept that mitosis should be based upon a dual principle. That is, one of the factors which make a cell capable of division is assumed to be endogenous (a "possibility factor"), while a second one ("realization factor") is exogenous although it may arise in the same organism.

These early experimental observations were interpreted in the following way: there exists a surface "principle K", which remains constant during cell growth, and also a "principle A" which increases in a metabolic manner (Gurwitsch, 1922). The main problem was to elucidate the nature of the exogenous principle. Initially it seemed natural to look upon it as a chemical substance. However, cell division frequencies should then be proportional to the relation of K to a constantly increasing A, which contradicts the established fact of a reverse linear relationship between cell division frequency and cell surface area. This contradiction led to the following suggestion: K and A sites are arranged

on a cell surface as a permanently changing spatial mosaic. It is the mosaic-like configuration which plays a decisive role, the perception of an exogenous impulse by a cell surface may be considered as a resonance event. This led to the hypothesis that the exogenous division stimulating principle is not a chemical substance, but instead an oscillation process which may be a radiation.

The experimental verification of the hypothesis that the exogenous factor is a form of radiation has evolved from the suggestion that at least some radiation should emanate from root cells into the surrounding space and that it would be most probable that detectable radiation would arise from the cone-shaped tip of an onion root. An adequate detector should consist of a second root with cells ready to divide and really dividing with a certain average frequency, but at the same time capable of increasing the frequency. The necessity for comparison with control cells was also obvious. In that respect onion roots are suitable objects due to their radial symmetrical arrangement. Therefore, the revealing of a difference in mitotic numbers between the "irradiated" and the "shadowed" sides of the meristem after a unilateral local stimulation from another root seemed to be fairly possible.

The first "mitogenetic" experiments conducted in 1923 were performed on about 130 root pairs (Gurwitsch, 1923). Already these experiments, in which a horizontally oriented inductor-root was brought to a distance of 1.5 to 2 mm from the medial surface of the meristem of the vertically oriented detector root during 1–2 h, gave distinct positive results: the number of mitosis at the medial zone of the "illuminated" side was 20–25% higher than on the other parts of the meristem. The physical nature of the mitogenetic factor was proven by using glass or quartz plates as filters and by a complete chemical isolation of the inducer from the detector sample. Later on, the signal spectral composition was shown to belong to the UV range, somewhat in between 190 and 300 nm.

Although Gurwitsch is credited with the discovery of mitogenetic radiation, there were several earlier reports of similar phenomena. Scheminzky (1916) detected some high-energy radiation from various biochemical processes by means of photographic plates. He used cultures of yeasts and bacteria to provide these biochemical processes. This work was confirmed in 1918 by Ludwig (1918) who also used photographic plates to detect emissions from fermenting yeasts.

The news about the discovery spread very quickly throughout the scientific and public circles, and a large number of investigators, among them physiologists, microbiologists, medical scientists, and physicists in Russia, Germany, France, Italy and other countries, tested the effects discovered by Gurwitsch and studied his hypothesis further. The Golden Age of mitogenetic rays lasted for about two decades and brought about a thousand of papers and several books (Gurwitsch & Gurwitsch, 1959). Gurwitsch's work was supported by many Russian workers and several Western workers (Borodin, 1930; Rahn, 1936; Wolff & Ras, 1932), but many others (Bateman, 1935; Hollaender & Schoeffel, 1931; Richards & Taylor, 1932) were unable to detect any mitoge-

netic effect. A problem is that most of the publications, containing a lot of valuable data, have been written in Russian and are hence almost inaccessible to the scientific community; although the early reviews (Bateman, 1935; Hollaender & Claus, 1937) and the excellent book by Rahn (1936) have described this early mitogenetic work in detail.

In view of the contradictory results obtained with biological detectors, some of the early workers, among them Bateman (1935) introduced physical detectors such as photographic plate and UV-sensitive Geiger tube in order to detect the UV photon emissions. In fact, the results using physical detectors were as variable as those obtained with biological detectors. These developments in combination with the disproving papers, the best known being that by Hollander and Claus (1937), Gray and Quellet (1933) and Lorenz (1934), played a fatal role in the whole story. It is worth mentioning, however, that the latter article seemed to be not so important scientifically. A number of scientists working in this field (not only those who worked with Gurwitsch, O. Rahn from USA among them) easily revealed some obvious experimental errors in this work which have not been hidden by the authors themselves. These errors included, among others, the use of too young yeast cultures for testing the mitogenetic effect, though it was many times pointed out by Gurwitsch and others that at this stage yeast cells are not sensitive to external photons. However, this criticism was ignored and the refutation of the existence of mitogenetic rays claimed by Hollander and Claus was given wide publicity, and the overall interest in and recognition of Gurwitsch discovery began to decline in West European countries and USA. Despite this, work continued in East European countries with surprisingly little acknowledgement of the negative results of the above Western workers. Another reason for the decline was certainly the World War II, destroying, to the greatest extent, just Germany and Russia—two centers of the most intense studies of the problem. One may add to this the subsequent Lysenko persecutions of biology in Russia. Only small remnants of the former laboratory of Gurwitsch continued to work in this field in very restrictive conditions after 1948. This group was headed many years by Gurwitsch's daughter Anna, also a Professor of Biology (Gurwitsch, 1988). Later, mitogenetic rays (i.e., UV emission associated with cell cycles) were detected with the use of electronic photomultipliers in several laboratories (Chwirot et al., 1986; Chwirot, 1992; Konev et al., 1966).

Studies on Photon Emission With Photomultiplier Tubes

The newly developed photomultiplier (PM) tube, which proved to be a very sensitive and reliable method for detection of very weak light, led to a limited revival of interest. The very weak light in the visible region was first detected in the 1950s. The first studies (Strehler and Arnold, 1951) involved photon emission from green plants, including three species of algae, following irradiation with visible light. In 1954 and 1955, Colli et al. described weak visible region luminescence from seeds germinating in the dark (Colli & Facchini,

1954; Colli et al., 1955). In the 1960s several Russian groups headed by Tarusov et al. (1967), Vladimirov (1966), and Zhuravlev et al. (1968) studied the visible region luminescence from many plants and animal species. Konev and coworkers (Konev, 1967; Konev et al., 1966) were the first to employ the UV-sensitive PM tube to detect UV photon emission from living organisms. They repeated some of the classical mitogenetic work using synchronized cultures of *Candida utilis* in order to determine whether UV photon emission was connected with cell division. They detected a UV emission peak which preceded the first wave of cell division by about 1 h and a second weaker peak which corresponded in the same way to the second synchronous division step. Konev's group studied (Mamedov et al., 1969) over 100 different species of organisms covering 8 systematic types, including 13 algal, 9 yeast, and 8 bacterial species. They detected photon emission from about a third of the algae, bacteria, fungi and insects examined, but in the higher plants and vertebrates all the species investigated displayed luminescence. Only the protozoa gave no detectable photon emission from any of the species studied. The question of the extent to which this is due to the detection technique itself is only partly answered. In this respect, it is interesting to note that, at least for one of the species of bacteria (*Escherichia coli*) which gave no detectable luminescence, subsequent workers (Tilbury and Quickenden, 1988; Wang et al., 1990) have observed significant photon emission. This is possibly due to the greater sensitivity of the more recent PM tubes.

Coming back to the problem of the authenticity of the data of Gurwitsch's school, we have to consider separately two questions: (1) Does ultra-weak photon emission of living systems in the visible and UV range really take place? (2) Does ultraviolet light really stimulate cell division? So far, a positive reply to the first question is today beyond any doubts—measuring photon emission of biological organisms is a routine procedure now. Before going into depth with the second question attention is paid first to the biochemical experiments following the detection of this photon emission: the question of photon emission origin.

Biochemical Mechanisms of Photon Emission

One of the most difficult problems was associated with the mechanisms of the generation of UV photons in living systems. By the end of the thirties, as a result of extensive studies with the participation of prominent physicists and chemists, it was concluded that the emission of photons by living systems may be considered as a kind of chemiluminescence due to the recombination of the free radicals which appear in a number of chemical reactions. In this paragraph we will consider primarily biochemical mechanisms by which living systems create electronic excited states and photons, and the link between them and physiological processes.

The emission of electromagnetic radiation with the energy $E = h\nu$ and the corresponding wavelength $\lambda = c/\nu$ occurs when an electric charge oscillates at

the frequency ν. In the spectral range 180–1000 nm covering the UV, visible and near IR, corresponding oscillation frequencies are $3 \cdot 10^{14}$–$1.6 \cdot 10^{15}$ Hz. Thus, the generation of photons requires two phases: (1) the energy pumping that promotes an electron to the excited level, and (2) radiative relaxation that creates a photon.

Living organisms can utilize a variety of energy forms and transform a fraction of them into an electronic or vibrational excitation. In photosynthetic bacteria and green plants, for example, the photoexcitation of bacteriochlorophyll or chlorophyll takes place and leads to charge separation and storage. A subsequent recombination of charge-separated molecular species results in photon emission in the red part of the spectrum, the so-called photosynthetic or delayed luminescence (Strehler's radiation). Heterotrophes employ free energy from the reorganization of chemical bonds of substrates in the consumed food. In this case the change of free energy is a part of the thermochemical effect of the chemical reaction (i.e., reorganization of bonds). The whole process can be classified as chemiluminescence, since the first phase is a chemical pumping or chemiexcitation.

Efficient emitters should have low-lying excited states and high values of the luminescence quantum yield. Therefore most presently known efficient chemiluminescent systems involve large molecules with easily polarizable and thus excitable π-electron systems, such as flavins, indoles, porphyrins, carbonyl derivatives of aromatic compounds, heterocyclic rings like purines and pyrimidines and species-specific compounds evolved in bioluminescent organisms, the so-called luciferins. These compounds have a relatively high quantum yield due to the short lifetime of the singlet excited state. Good candidates for direct emitters, especially in the near UV range, are tryptophan (Slawinski et al., 1980a) as well as nucleic acids (reviewed in Jezowska-Trzebiatowska et al., 1987; Popp et al., 1978; Popp, 1984). Different ionic and/or radical forms of oxidized/reduced flavins that are important components of the respiratory chain also exhibit strong and broad absorption bands as well as emission in a very broad spectral range from near UV to near IR. Furthermore, the energy levels of the lowest electronic states of O_2 and its dimole (excimers) require relatively small portions of the excitation energy and reveal many radiative transitions, including transitions in the UV-region.

In general, the explanation of emission in terms of chemiluminescence did not deal with the bio-informational aspect of photon emission. Coming back to the problem of the Gurwitsch's school we should consider the question: Does the UV or visible light really stimulate cell division or other physiological processes? In fact, most of the biochemists involved in photon emission studies considered radiation as a waste of energy without any information for the cell. However, regarding this question, one should really ask: How could photon emission be discovered in 1923 if it did not provoke an increase in cell division rate? The mitogenetic effects were checked in Gurwitsch's laboratory almost every day, since the yeast bud counting was used as a routine proce-

dure. In the course of this discussion many times the counting method was criticized as too subjective and as unable and not sufficient to demonstrate significant effects. For those who really worked with these counting methods this criticism does not sound like substantiation. For each single test a statistically sufficient amount of yeast cells (no less than 2000) was to be checked for the presence of buds, and the blind counting (without knowing what was counted at the moment) was used as a rule. Notwithstanding these arguments and the necessity to develop computerized measurement techniques, the informational aspect of photon emission is certainly worthy of further consideration.

The Informational Character of Bio-Photons

The search for evidence of the 'informational character' of ultra-weak photon emission from biological systems was stimulated by Popp in the 1970s. He introduced the term 'bio-photons' in 1976 (Popp, 1976). Like 'bioluminescence' which specifies luminescence of biological systems, bio-photons refer to the biological system as a whole. The emission of single photons is assumed to point more to a biological quantum phenomenon than to ordinary luminescence. The coupling of bio-photon emission to biological quantum phenomena is most evidently seen in the information underlying cell division. In this view a cell is part of a larger structure in which cell loss rate is compensated for rather exactly by the cell division rate, in order to avoid serious disease like abnormal swelling or shrinking of tissues, including cancer. Furthermore the tissue structure contains information that is more than that of the individual cells. It has been argued that if growth regulation of biological systems is based on information originating from the death of cells, it is not possible to explain this regulation by messenger molecules from individual cells. Rather, electromagnetic interactions are suited for transferring the necessary messages and have to take the role of regulators of a biological system in order to explain many, if not all regulatory functions (Popp and Chang, 1998). Consequently we expect some correlation between growth and bio-photon emission.

VanWijk and co-workers were the first to show an effect that light radiation from a cell population is not simply correlated with its cell number. They observed the difference of light-induced delayed emission of bio-photons with increasing number of cells for normal cells and tumor cells (Schamhart and VanWijk, 1987; VanWijk and Schamhart, 1988; VanWijk and Van Aken, 1991, 1992). As expected, the bio-photon emission has just the opposite characteristic for normal cells than for tumor cells. Whereas normal cells show decreasing emission with an increasing number of cells, the photon emission of tumor cells increases in a nonlinear way to higher and higher values, displaying thus a qualitative, not only a quantitative, difference. Photon emission was also cell type dependent, multipotent fibroblastic cells showing the strongest emission (VanWijk et al., 1993; 1995a; 1995b). Furthermore, it is worthwhile to note that the relaxation after light illumination follows a hyperbolic ($1/t$) law (where t is the time) rather than an exponential $\exp(-t/T)$ law (where T is

the decay constant; Schamhart and VanWijk, 1987; VanWijk et al., 1995a, 1995b, 1997). Similar results were obtained for other cells by Scholz et al. (1988). They confirmed that the delayed luminescence relaxation of normal tissue with increasing cell density conforms more and more to an hyperbolic function, while that of tumor tissue displayed increasing deviation from hyperbolic decay and increasing agreement to exponential decay with increasing cell density.

These observations cannot be explained in terms of linear physics, since with increasing optical density of the tissue, according to the laws of linear optics, the saturation may be understandable, but not the decrease after saturation. However, it is in accordance with the idea of a coherent communication not only between neighbor cells but among all the members of a cell population. As soon as the integration of a new cell into the population by cell division does not result in an increasing coherence of the system, the information for cancerous growth will arise. Consequently, the model of a coherent bio-photon field, providing the basic communication of the cells in an organism, might help to understand cancer growth in terms of rather fundamental properties of a coherent field.

In order to explain non-linear optical phenomena of biological systems, it is important to remember the general but at the same time basic property of all biological tissues of representing optically "dense" matter. This means that the intermolecular distances are small compared with the wavelength of the light. Under these conditions the theory of Dicke (1954) has to be applied in order to understand the interaction of light and matter. According to Dicke, spontaneous reemission of absorbed light is impossible as soon as the intermolecular distance is significantly smaller than the wavelength. Rather, the interaction of the pigment molecules and the photons split into two new "regimes" of super- and sub-radiance. Super-radiance corresponds to constructive interference of light waves cumulating up to coherent light flashes which are then emitted in relatively short time intervals. Sub-radiance is defined as the destructive interference of the light waves within the system of absorbing molecules. The result is "delayed luminescence" of coherent light waves which relax according to hyperbolic functions. Just this situation is displayed in biological systems. Consequently, the explanation of the results on normal and tumor cells follows the general theory of Dicke.

A second series of experiments showing similar results has been performed by Galle et al. (1991). He investigated the spontaneous bio-photon emission of Daphnia magna in dependence on the number of animals in the quartz cuvette of fixed volume. The animals were female only of the same genetics and about the same size and development stage. Instead of obtaining increasing bio-photon emission with increasing number of animals, Galle observed in several experiments maxima and minima of photon emission. One of the minima corresponds to a 'natural' distance which is preferred by the animals if they are living in freedom. It has been argued that an interpretation of the results by a

"collision" model or by "chemical communication" is not possible (Galle, 1992).

A third series of experiments has been performed on Dinoflagellates and Thailand fireflies which show in addition to bio-photon emission distinct bioluminescence. The fascinating feature of their bioluminescence is synchronous flickering as soon as they make contact with each other. A careful analysis of the synchrony showed that it cannot be explained in terms of mutual excitation with light. A striking observation is that even if they are separated, synchronous bursts can be observed as soon as they become aware of an external perturbation. A further important factor in understanding the mechanism is the fact that in the case that a shutter between them is opened, the total intensity of the whole system is not simply the sum of both. Chang and Popp (1998) have tried to specify the nature of intercellular communication by light by investigating again in detail the synchronous flickering. They constructed a light-double chamber in which two samples can be connected and disconnected by a shutter between them. Consecutive opening and closing of the shutter enables non-substantial communication between the samples or blocks it, respectively. At the same time the two photo-multipliers which are connected to each of the samples register their photon current.

In the meantime several examples have been studied on bio-information or cell to cell communication without chemical mediators or special messenger molecules such as hormones, growth factors and neurotransmitters. In 1992, G. Albrecht-Buehler reported that cells were able to detect the orientation of others by signals that penetrated glass but not thin metallic films and that, therefore, appeared to be carried out by electromagnetic radiation (Albrecht-Buehler, 1992). Golantsev et al. (1993) reported that a mammary explant of lactating mice stimulated with some secretion-regulative hormones such as oxytocin, acetylcholine, epinephrine and norepinephrine can induce protein secretion in the other mammary explant of the mice even when separated by quartz glass. Shen et al. (1994) found that the neutrophils stimulated to undergo respiratory burst can activate a second, chemically separated, but optically coupled population of neutrophils. The response of the latter was visualized as a temporary rising of their low-level chemiluminescence and enhanced generation of superoxide radicals detected by both the reduction of ferricytochrome c and spin trapping.

Kuzin and Surbenova (1995) reported that seeds (*Raphanus sativus*) acquired a new property after they were irradiated at low dose: some hours after irradiation the seeds exert distant influence on the native seeds used as controls. The distant influence is to accelerate germination and development of the native seeds (160-180% of the rate for control samples).

More recently, Shen et al. (2000) extended their experiments to the question of whether the chemiluminescence burst of the neutrophil cells stimulated by phorbol myristate acetate (PMA) or zymosan could be modulated by the presence of a separated neutrophil cell population in close vicinity. The results of

all 12 independent tests made during 1996–1997 demonstrated 9 tests with a significant enhancement of the respiratory burst of the PMA-stimulated neutrophil cells by the presence of a separated but optically coupled neutrophil cell suspension, but 3 tests yield negative outputs. The same experiments were repeated in 1998, in which 9 independent tests were conducted. The enhancement of the respiratory burst of the PMA-stimulated neutrophil cells by the presence of a separated but optically coupled neutrophil cell suspension was observed in 8 tests, and only 1 test showed a negative outcome. However, the negative outcome was not significant.

Models for Explaining Photon Emission From Collective Molecular Interactions

The following question arises: Is it possible that molecular interactions collectively accumulate small portions of energy until the threshold value $E \simeq hc/\lambda_{min}$ is reached? There are at least two classes of luminescence generated without chemical reactions in strict sense, i.e., without reorganization of strong chemical bonds. The first class includes crystallo- and lyo-luminescence, where light emission accompanies growth and solubilization of crystals. The second class includes the emission associated with the penetration of water into bio-polymers and dry biological objects such as seeds and spores (Boveris et al., 1983; Slawinski et al., 1980b, 1981). The existence of photon emission in these processes strongly suggests that small portions of energy can indeed accumulate to the extent necessary for electronic excitation. With respect to cellular mechanisms of certain processes involving weak intermolecular couplings that probably result in photon emission, the role of DNA, biomembranes and cellular water have been discussed.

The hypothesis that photon emission originates from the relaxation of superhelical DNA is based on the possibility of excimer formation of polynucleotides at room temperature within the lowest long-living triplet states of DNA. The excimer complex is relatively stable and forms a photon trap since its free energy is lower than that of the molecular fragments. The natural tendency of exciplexes and excimers to absorb photons and to create excited states associated with ordered and more compact biostructures, e.g., condensed chromatin in the nucleus, fits well with the idea that the relaxation of DNA superstructures releases photons (Nagl and Popp, 1983a, 1983b, 1987; Popp et al., 1978; Popp, 1984; Popp and Chang, 1998; Rattemeyer et al., 1981). In this respect the biophoton emission of fractionated mammalian cells are of interest (VanWijk & Van Aken, 1991; VanWijk et al., 1995a, 1995b, 1997). Biophoton emission was detected in fractions containing nuclei and structured DNA. However, emission was not detected in purified DNA, neither was it in cell fractions containing cytosol, mitochondria, or ribosomes.

Another hypothesis is based on molecular interactions in the electric field of bio-membranes. Electric fields in biological microstructures can reach very high values of the order of 10^6–10^8 V/m. The existence of such high field

strengths implies that non-linear responses of molecular interactions should be taken into account. Every electrically charged particle passing the membrane is exposed to this field and its polarization may be dramatically changed. The energy which an ion gains in such a field is on average 10 kJ/mol. About 20 accelerated ions have to interact within a limited space and time to accomplish the energy accumulation necessary for the electronic excitation (Slawinski, 1988). The probability of such an event would be extremely low but finite, fitting well to the extremely low luminescence yield of the order of 10^{-14}–10^{-10} observed, e.g., in the case of crystalloluminescence.

A third hypothesis is based on collective excitations in cytosol. The analysis of the water-ion macromolecule system in membrane structures shows that cellular water exists in a physical state sufficiently ordered to exclude solutes, e.g., certain ions, and to create an extremely polarizable medium with $H_5O_2^+$ or $H_3O_2^-$ ions in which metastable, dynamic states are possible. The evidence for this comes from a cooperative interaction between the majority of ion-absorbing sites that replace K^+ by Na^+ ions. The sigmoidal nature of the equilibrium distribution isotherm of cellular K^+ and Na^+ is analogous to critical or collective phenomena in general (Clegg, 1983; Nagendank, 1982). Some evidence that collective interactions can produce macroergic effects leading to electronic excitation comes from experiments with water-induced luminescence of dry seeds (Slawinski et al., 1980b) or spores of fungi (Slawinski et al., 1981). The addition of water produces instantaneous weak luminescence and is related to physico-chemical processes earlier than the onset of germination, probably involving hydrophilic coherent interactions within a limited space at the water-macromolecule boundary. Whether a sort of Bose condensation of coherent photons or the accumulation of energy in molecular constellations accounts for these phenomena remains to be decided. It must be kept in mind, however, that most of the above considerations require further verification.

Conclusion

There are still a large number of biological phenomena and events that cannot be adequately explained, or even simply described, such as regulation of cell division and cellular differentiation. How is the program of growth controlled, and how does the ordered growth come to be disturbed?

Paying attention to the devotion of the first generation of researchers that studied the possibility of division regulation by endogenous radiation, we have also looked at the difficulties and the "dead periods" in their research, which unfortunately did not lead to discussion on the causes. Some skeptically minded persons used this ambiguity as a reason to neglect the whole field. It may be suggested that the main reason for rejecting the Gurwitsch's approach by the majority of his contemporary scientific community was the extraordinary conclusions following from the mitogenetic experiments, rather than the incorrectness of the experiments.

The second generation of researchers that verified the existence of photon

emission from biological organisms and cells no longer made use of the experiences obtained by the first generation. Instead this field was dominated by the biochemical approach and led to the identification of numerous metabolic and enzymatic steps that could be responsible for photon emission by organisms and cells.

The question of the existence of radiation with a bio-informative character has been the subject of the third generation of researchers in the field. Can long-range electromagnetic waves and fields be seen as the basis of biological organization? The approach of this generation is to break down the dichotomy between the biological and physical approaches in this research. 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. One of these principles may be found in coherence. Although this topic is now studied by these third generation scientists all over the world, it also led to an international co-operation of these interdisciplinary scientists with a major meeting place at the International Institute of Biophysics in Neuss, Germany. The institute's primary purpose is research of some "integrative biophysics" that pays attention to the properties of coherence, long range interactions, information and communication in living organisms with biophotonic or bio-electromagnetic techniques. The research activities can now be recognized by the increasing literature in this field as it is presented in reviews and books (Beloussov and Popp, 1995; Beloussov et al., 2000; Chang et al., 1998; Jezowska-Trzebiatowska et al., 1987, 1990; Popp et al., 1988, 1992, 1994; VanWijk et al., 1992; Zhang et al., 1996). This literature demonstrates the richness of information which can be retrieved from measurements of photon emission. The present review may offer the opportunity to take part in the discussion in order to reach a better understanding of radiation from (and within) biological matter.

Notes

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