Biophotonics and Coherent Systems in Biology

Alexander Gurwitsch (first row, 3rd from the right) and his associates near the Taurida University laboratory, where mitogenetic radiation was discovered (1924).

Participants of the 3rd International Gurwitsch Conference near Gurwitsch's former laboratory (2004).

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With 118 Illustrations

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EDITORIAL PREFACE

The 3rd Alexander Gurwitsch Conference on Biophotonics and Coherent Systems in Biology was held from September 27th to October 2nd, 2004. Contrary to the first two conferences from the same cycle which took place at Moscow State University in 1994 and 1999,[1,2] the latter one was hosted by V.I. Vernadsky Taurida National University (Simferopol, Crimea, Ukraine). In no case was this occasional. Modern Taurida University (re-established under this name a few years ago) regards itself as an inheritor of the same name institution that was opened in 1918 and existed as a University until 1924 (when it was renamed as a Pedagogical Institute). In many respects, the first Taurida University was a remarkable organization. Under severe conditions of a starting post-revolutionary civil war in Russia, when normal research and educational activity in the main centers (such as St. Petersburg and Moscow) became almost impossible, Taurida University succeeded in collecting a brilliant company of professors and students who did not want to emigrate from Russia but were willing to continue their activities in their native country. Among them was a famous geochemist and philosopher, Vladimir Vernadsky, who was for some time the Rector of Taurida University and who gave his name to the modern Taurida University. Soon he became a close friend of Alexander Gurwitsch, who was elected as a Professor of Histology of this University already in 1918. It took meanwhile almost a year for him together with his family to reach a relatively peaceful Crimean land by going from starving Petrograd (former and later St. Petersburg) through an enormous territory of Russia and Ukraine already separated into several fighting estates. Although the situation in Crimea was also quite far from idyllic, and a civil war with all of its shortages and cruelties soon reached this area, Taurida University could provide much more academic freedom and cooperation between its outstanding members than any other institution in those days in Russia. For Gurwitsch, who originated from Ukraine, wonderful nature of the Crimean peninsula was also a source of inspiration. The first few years of his work in Taurida University turned out to be extremely fruitful. Then he made his famous "onion experiment", which opened a door to a miraculous world of biophotonics and electro-magnetic biology, and gave a first sketch of his "embryonic field" theory. It was also amazing how rapidly developed the biophotonic studies in Taurida University and how soon they became known to the worldwide scientific community. The main reason was that not only the professors, but also the students of this University were outstanding. Some of them continued to work in this field for their whole life. To be mentioned among them is a later well-known cytologist, Semen Zalkind, and a biophysicist, Gleb Frank, who

became a member of the Soviet Academy of Sciences and the founder of the main center for biophysical research in the Soviet Union and now in Russia, the Institute of Biophysics in Puschino.

Being eager to revive these glorious traditions, the authorities of the modern Taurida University started the Conference by a ceremony of opening a common Gurwitsch-Frank memorial desk at the main University entrance. The ceremony was preceded by a special University session with Dr. V. Lavrov lecturing about the history of Taurida University in Gurwitsch's times and Prof. V. Voeikov's lecture about Gurwitsch's main works. By a miraculous occasion (nobody arranged it intentionally), this ceremony took place exactly on Alexander Gurwitsch's 130th birthday!

On the same day, an unforgettable enterprise was the excursion to the house where Gurwitsch's lab (and his family flat) was located and where he made his onion experiments. The beautiful villa safely survived the Second World War and was only slightly redesigned. We, the conference participants, made a group photo at almost the same place where the Gurwitsch group was photographed exactly 80 years before (see two photographs on the frontispiece).

The Conference collected several dozen participants from Russia, Ukraine, several European countries, USA, and Israel. Unfortunately, due to traveling problems, several potential participants, including IIB members, could not personally attend the conference. However, they presented the contributions that we included into the volume. Taken together, they give a representative picture of the modern state of biophotonics and the related branches of biology and biophysics.

By the Editors view, the main novel feature of the 3rd Gurwitsch Conference, as compared with the previous ones, is the extension of biophotonics from its traditional optical wavelength range toward that including smaller electromagnetic frequencies and stationary fields. In other words, biophotonics becomes a part of a common science that may be called the electromagnetic biology. Such an extension is far from being formal: a main conceptual basis of this new trend of science is to a great extent borrowed from the modern biophotonic studies. This relates most of all to the concept of coherence. It is this concept that permits to explain the biological effects not only of the UV and optical wavelengths range, but also those of much smaller frequencies. The idea of coherent regimes of molecular interactions as well as the related views and experimental findings seem to be of an utmost importance and heuristic power not only for electromagnetic biology *per se*, but also for the cell and organismic physiology.

Although several papers from this volume are treating different matters, some of which are only indirectly linked with biophotonics in *sensu stricto*, we decided not to subdivide the entire volume into different sections. By arranging

the papers, we put in the beginning those completely or partly devoted to the biophoton emission. These were followed by the papers treating electromagnetic fields, and at the end of the volume we put the contributions not related to electromagnetic events but associated with the concept of a coherence in its broader sense, including even sociological and philosophical aspects.

One of the aims of the 3rd Alexander Gurwitsch Conference was to emphasize the links between the pioneer Crimean experiments and modern biophotonics. Accordingly, we found it suitable to end the Conference volume by a brief tribute to the person who did more than everybody else for promoting a continuity of this research line – Professor Anna Alexandrovna Gurvich (1909-1993).

Together with all the Conference participants, we express our deep thanks to the Rector of Taurida University, Professor N.V. Bagrov, to the Deputy Rector, Professor V.N. Berzhansky, and to all the members of the Organizing Committee of the 3rd Alexander Gurwitsch Conference for their wonderful acceptance at the land of Crimea, making the conference a remarkable scientific and cultural event. Our special gratitude comes to Dr. N.D. Vilenskaya who took on herself the burden to format the whole volume. We thank also Mr. A. Johnson and Mrs. K. Zimmer from Springer for their help in issuing this book.

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CONTENTS

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FROM MITOGENETIC RAYS TO BIOPHOTONS

Vladimir L. Voeikov and Lev V. Beloussov*

> Persons with the most complete scientific worldview for their time always belong to "scientific heretics", rather than to representatives of the scientific mainstream. Contemporaries are unable to distinguish them from those deluded... Their opinions do not attract our attention or arouse our dissatisfaction and rejection.
>
> Academician Vladimir Vernadsky
>
> "On the Scientific Worldview", 1904

1. NON-ACCIDENTAL DISCOVERY OF MITOGENETIC RADIATION

In the full swing of a civil war, when terror, hunger, and ruin were reigning in Russia, a new university admitted first students at the far South of the country - in Crimea. Taurida University remained at that time the only self-governed, free university in the whole of Russia. Outstanding Russian scientists, those who did not want to leave their country, gathered there. Such prominent figures as physicists Alexander Ioffe, Igor Tamm, geologist Vladimir Obruchev, and biologists Michail Zavadovsky, Alexander Lubischev were among them. In 1920, academician Vladimir Vernadsky was elected Rector of Taurida University by the Professor Counsel.

The Chair of Histology of the Medical and Natural Sciences faculties was headed by Professor Alexander Gawrilowich Gurwitsch. He was born in 1874 in the Ukrainian town of Poltava, and after graduation from the Medical faculty of Munich University worked for nearly a decade in German and Swiss leading biology centers. He was deeply interested in one of the most enigmatic problems in biology - in morphogenesis - and desired to understand the mechanism of emerging of complex tissues and organs, of organisms with unique architecture from rather primitively structured embryo cells.

In 1906, A.G. Gurwitsch moved to St. Petersburg were he was elected professor of histology at Bestoughev Women College. In 1912, he published an

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original theory of embryonic development in which for the first time in biology the term “field” belonging to the realm of physics was used (1). According to Gurwitsch’s Morphogenetic Field theory, behaviour of both individual cells and organ rudiments is controlled by a field of forces common to all the elements of an embryo. This field regulates behaviour of individual cells in a developing embryo, routes their movements, controls their divisions and differentiation, and evolves itself with embryo growth. Gurwitsch was cautious enough and did not specify the physical nature and initial sources of this field.

Morphogenetic Field theory explained many facts of the process of embryogenesis, allowed to predict further stages of morphogenesis based on the analysis of the actual disposition of cells in the embryo, and attracted great interest. But the number of the opponents of the Field theory much exceeded that of its supporters mainly because the theory did not keep within the postulate that had already become the cornerstone of physiology and biochemistry of the XXth century: all biological phenomena including the process of development of a living organism result from mere summations of usual chemical processes. Gurwitsch considered that experimental evidence can persuade his opponents, but after the Bolshevic revolution it was impossible to think of experimental work in Petersburg, and he moved to Crimea.

In the process of embryonic development, the number of cells increases as they divide. Gurwitsch questioned which factor or factors cause cell reproduction. He studied statistical distribution of mitoses, that is of cells being in the process of division into two, and came to the conclusion that mitosis occurs when two independent events coincide. The first of them is the resumption of cell maturation. A cell should synthesize all the components necessary both for the process of mitosis and for daughter cells. Gurwitsch defined this condition dependent on the given cell activity - the “possibility factor”. But even a mature cell does not enter mitosis unless it is triggered by some external impulse, “realization factor”, which can originate from the organism to which the cell belongs.

Reflecting upon the nature of the external signal, Gurwitsch noticed that in symplasts (in tissue regions containing many nuclei non-separated by cell membranes), all the nuclei either divide synchronously or are involved in common waves of mitotic divisions. Meanwhile in tissues consisting of uninucleated cells, these always divide asynchronously. This pointed out that a cell membrane (or cell-environment interface) was an organ perceiving external signals for cell divisions. For defining the molecular structures of cell surfaces responresponsible for such a perception, Gurwitsch used a term “receptor” long before it was established in the modern molecular biology.

For getting more precise information about these receptors properties, Gurwitsch studied the dependence between the length of onion root cells and frequency of cell divisions. If assuming that: (1) the cell elongation is associated with random insertion of new non-receptive surface particles between the receptors and (2) the perception of mitotic signals is proportional to density of receptors (as should be expected if the signal is a kind of a soluble chemical “hormone”), such dependence should be inversely proportional and fit the first order hyperbola. However, he found that it was and much steeper than the first order hyperbolic one (Fig. 1). This dependence indicated that “receptors” do not

act as independent units. Rather, they create a kind of a holistic (cooperative) system, which may have the properties of a resonating contour. From this Gurwitsch concluded that the perceived signal should be a physical factor triggering cell division on the principle of resonance. For example, this factor could be photons because of their wave nature. In his later papers, Gurwitsch numerously emphasized that such a conclusion was no more than tentative, but it gave him the idea of his famous "onion experiment" which, as we can see, in no way was occasional.

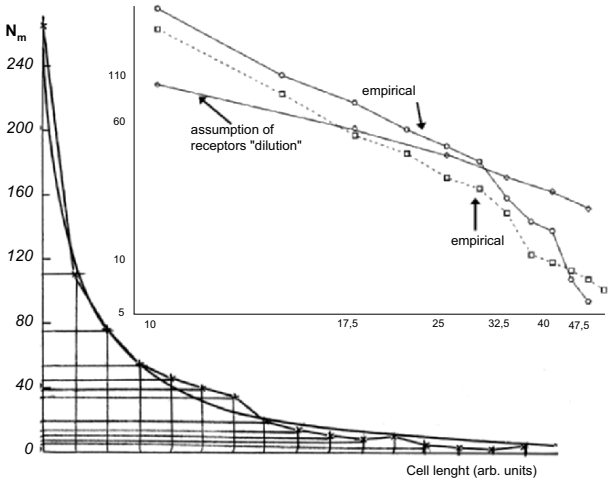

Figure 1. Dependence of the number of mitoses in an onion root (N_m – ordinates) on cell lengths (arbitrary units, abscissa). Left bottom plot – original Gurwitsch's data in linear coordinates and their best fit. Upper plot – two sets of experimental data and theoretical curve on the assumption of receptors "dilution" with a cell elongation in log-log coordinates.

2. BIOPHYSICAL PECULIARITY OF MITOGENETIC RADIATION

In 1923, Gurwitsch performed the crucial experiment for the evaluation of his hypothesis that photons were triggering cell divisions (Fig. 2). A tip of an onion root - the inducer - was directed at the wall of another onion root - the detector. After they had been kept for some time in this configuration, the number of mitoses at the detector side facing the tip of the inducer root significantly exceeded that at the opposite one. If a glass plate was introduced between the inducer and the detector, there was no stimulation of mitotic activity. A quartz plate shielding the tip of the inducer root did not interfere with its action. If the tip of the inducer was aimed at the metal mirror in such a way that its reflection fell onto the wall of the detector, stimulatory action again was observed.

These results could be explained neither by chemical nor by mechanical action of one root on another. The most plausible explanation of the effect was the following: a living organism can emit photons that stimulate cell divisions. These photons belong to the ultraviolet region of the spectrum since quartz but

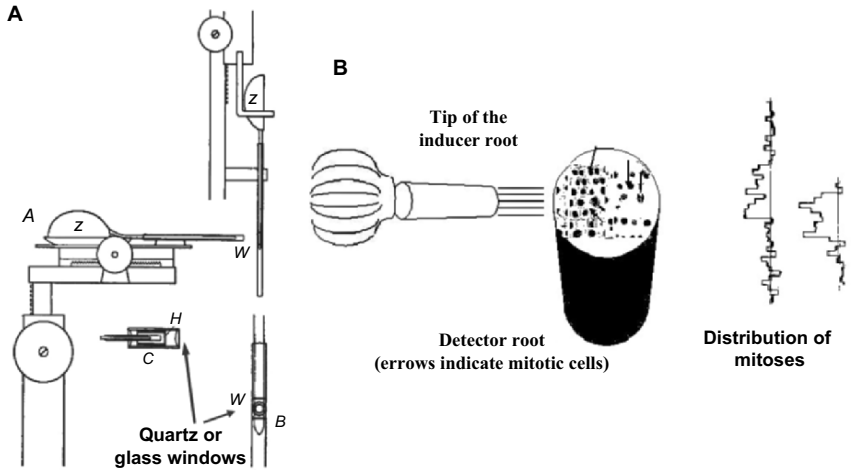

Figure 2. Schematic of "onion" experiment of Gurwitsch. **A**. Installation of an inducer root (horizontal) and a detector root (vertical) on moving tables of microscopes. *Z* – onion bulbs, *C* – tip of the inducer root fixed in an air-tight chamber, *H* and *W* – quarts or glass windows. **B**. Sketch of experimental results evaluation. A detector root was sliced below and above the "irradiated" zone and an excess of mitotic cells on the left (irradiated) or right (non-irradiated) sides of the root on each slice was calculated. Two indented lines at the left illustrate the results of two representative experiments. Significant excess of mitotic cells on the left side over the average distribution was observed in the irradiated region.

not glass is transparent for them. That is why photonic emission from a tip of the root stimulating mitoses in another one was named "mitogenetic radiation" (MGR) (3).

It is well-known that UV-light is hazardous for living cells. However, when the light beam of an UV-lamp was attenuated several thousand times, the number of mitoses increased. Thus, the conclusion that UV-photons induce the performance by a living cell of its major function - reproduction - had been proved. It also turned out that the effect of light on living systems strongly depends on its intensity and duration of action: excessive illumination resulted in suppression rather than stimulation of cell divisions.

In 1924, Professor Gurwitsch was elected the head of Histology Department at the Medical Faculty of Moscow State University, and the investigation of the new phenomenon was continued there. It was shown that MGR is produced by various animal and plant tissues, by microorganisms. As regards onion roots, it turned out that when a root was cut off the base of a bulb, it immediately ceased to emit MGR. On the other hand, the basal membrane of the onion bulb and even minced tissue was an effective source of MGR. From this two important conclusions could be gained. First, the original source of MGR was an onion bulb tissue where intensive respiration took place. Second, as it was highly unlikely that photons originating in the onion basement membrane could travel along the root without being absorbed, one should conclude that waves of electronic excitation can propagate in a living tissue on macroscopic distances analogous to a chain burning in a Bickford's fuse. The reality of dissipation- and radiationless propagation of electronic excitation was later confirmed by Gurwitsch and

colleagues in *in vitro* experiments and in physical-chemical aqueous model systems (see below).

Besides onion root cells, many other capable to divide cells could serve as MGR detectors, but an ordinary yeast culture turned out to be the most convenient test-system. It was irradiated with an MGR source at a lag-period, and the surplus in the number of mitoses in it over the control culture was calculated at the early stage of exponential growth. If cells were irradiated already at the phase of exponential growth, or at the stationary phase, no effect was observed. On the other hand, an yeast culture itself was the most efficacious source of MGR at the exponential stage of its growth, when the intensity of cell divisions was the highest. From this it followed, that MGR emerged due to high metabolic activity and that MGR in its turn induced metabolic processes. From the technical point of view, investigation of MGR needed understanding of physiology of both biological detectors and emitters of this radiation, and a lot of studies which allegedly refuted MGR existence were methodologically ignorant. Though rather elaborate, this method was very sensitive and served as an excellent tool for MGR studies in the following years (4).

An important observation was made by Gurwitsch's student Gleb Frank (he later became a Member of the USSR Academy of Sciences, founded and headed the Institute of Biophysics of the USSR Academy of Sciences). Frank made spectral analysis of MGR from different sources using plates with east cultures as detectors. UV nature of MGR was again proved: cell divisions could be induced by any photons in the region between 190 and 280 nm in the darkness and up to 326 nm if the detector cell population was illuminated by even a dim visible light. MGR spectra from various sources looked as sets of distinct bands. The latter varied in width from 25 to 0.5 nm. Each individual source of MGR produced a spectrum with the unique set of bands (Fig. 3).

This allowed obtaining "finger-print" spectra for several enzymatic reactions, to identify substances capable to scatter or to re-emit MGR of specific wavelengths. Physiological changes of a particular biological source were followed with spectral changes of its emission. MGR spectral analysis became one of the most informative methods in Gurwitsch's laboratory (5).

Though the notion of most properties of MGR was obtained based on its biological effects, in the 1930s UV-radiation emitted by some biological objects and chemical reactions was successfully registered in several laboratories using physical detectors - modified Geiger-Mueller counters. Their photocathodes were made of materials having maximal light sensitivity in the range of 190-280 nm and practically insensitive to visible light - copper, magnesium, aluminium, or their compounds. When such a material absorbs UV-photons it emits photoelectrons that trigger a gas discharge in a counter (6, 7, 8). It was shown with these counters that intensity of UV-photon emission from developing frog eggs or a nerve-muscle preparation excited with an electrical current is very small: 10-10000 photons (equivalent of 10^{-10} - 10^{-8} erg) per 1 sec from 1 cm^2 of the emitting object.

When such weak light beam is divided by a spectrograph prism into multiple bands, the intensity of the narrowest of them should barely exceed single photons per 1 second. If so, then single photons are able to induce an "epidemic" of mitoses in a yeast colony or in another biological MGR detector.

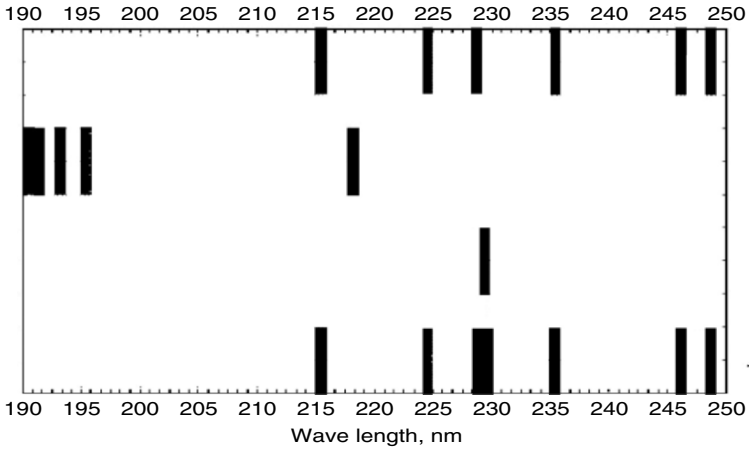

Figure 3. Spectra of MGR emitted by different reaction systems *in vitro*: 1st raw – hydrolysis of a nucleic acid or lecitin by phospatase, 2d raw – sugar fermentation, 3d raw – reaction of glycin autoxidation induced with glycin solution irradiation with MGR, 4th raw – same as above after addition of sodium phosphate.

Such a conclusion is to be made since only an "epidemic" of mitosis can be registered as a significant effect over the normal number of them in the control non-irradiated sample. How is it possible that a single photon can produce such a strong effect? Gurwitsch suggested that amplification of the initial signal is caused by secondary emission: a cell that happened to catch a photon becomes a secondary emitter of MGR. It may not enter the mitosis itself, but serves to "multiply" photons by a branching chain reaction mechanism. Later this suggestion was proved experimentally (9).

3. SOURCES OF ENERGY FOR EMERGENCE OF MITOGENETIC RADIATION

All living systems exist at mild temperatures and their bioenergetic facilities are generally considered to be satisfied by portions of energy stored in ATP molecules not exceeding 0.5 eV (7-10 kcal/mol). Energy of quanta of MGR reaches >8 eV (150 kcal/mol). This discrepancy for many decades was one of the obstacles for acknowledgement of the reality of MGR by biochemical and biophysical community. However, the preliminary answer to the question of the ultimate source of such high density energy that is released as mitogenetic radiation was received by Gurwitsch and his colleagues as long ago as in the 1930s (10).

It was discovered that MGR accompanied enzymatic and non-enzymatic hydrolytic and glycolytic reactions *in vitro*, as well as usual chemical reactions such as base-acid neutralization, redox reactions, and even dissolution of salt crystals in water or sol-gel transitions in aqueous solutions if and only if aqueous solutions in which the reactions were running were contacting air. For hydrolytic reactions, illumination of the reaction system with blue-green or

shorter wavelength light was also necessary for MGR emergence. Gurwitsch calculated the energy balance of such reactions and came to the conclusion that if energy for oxygen activation is provided, MGR arousal is not forbidden by the laws of thermodynamics. Let us take as an example hydrolytic reaction catalyzed by urease:

$$(NH_2)_2C=O + H_2O \rightarrow 2NH_3 + CO_2$$

This reaction is nearly thermoneutral, though energy of activation (or creation by the enzyme of an appropriate condition for reagents interaction) is needed for conversion of urea and water into ammonia and carbonate. In any case to convert reagents into products, the former should be dismantled into radicals:

$2H_2N\bullet$, $\bullet\bullet C=O$, $2H\bullet$ and $\bullet O\bullet$ (dots here designate unpaired electrons).

To break down urea to radicals and water to atoms, a total of 120+220=340 kcal/mol is needed. When these radicals recombine to 2 NH_3 and CO_2 approximately the same quantity of energy is released (87+87 = 174 kcal/mol and 167 kcal/mol, a total of 341 kcal/mol), thus this *chemical* reaction cannot provide energy for MGR. Indeed it does not emit MGR in the absence of oxygen. However, if energy no less than 118 kcal/mol is provided for oxygen molecule decomposition to two atoms $\bullet O\bullet$, "side" reactions may occur in which radicals arise from decomposition of initial reagents and oxygen atoms:

$$\bullet O\bullet + H_2O \rightarrow H_2O_2 + 51 \text{ kcal/mol}$$
$$H_2N\bullet + \bullet NH_2 \rightarrow H_2N - NH_2 \text{ (hydrazin)} + 69 \text{ kcal/mol}$$

This energy fully compensates energy expenditure for urea decomposition, and two radicals, to be more precise, two bi-radicals, carbonyl and oxygen atom, are left. Upon recombination of these bi-radicals, when four electrons simultaneously cancel each other's spins, an energy quantum, equivalent to the so-called "vacuum ultraviolet", is released:

$$\bullet\bullet C=O + \bullet O\bullet \rightarrow CO_2 + 167 \text{ kcal/mol } (\cong h\nu\ 170\ \text{нм})$$

If such high energy packages are generated in a milieu where appropriate fluorescents may be excited by them, all the array of photons with $\lambda \geq 170$ nm may be emitted. Indeed, as it can be seen from spectrograms presented in Figure 3, the short wavelength MGR photons with $\lambda=192$ may be registered.

A necessary condition for the realization of such a scenario is splitting of oxygen molecule into two atoms with an energy quantum equivalent of a photon of $\lambda \leq 235$ nm (118 kcal/mole). Indeed illumination of the reaction systems in which hydrolytic reactions proceed with visible light was needed for the emergence of MGR, and Gurwitsch suggested that only those visible photons were effective, energy of two of which could be pooled to the energy of one UV-photon with $\lambda \leq 235$ nm. If this suggestion was right, illumination of

solution with violet or blue-green light (up to $\lambda \leq 470$ nm) will be effective, while its illumination with more long-wave light will not support MGR emission. Experiments fully confirmed this hypothesis. Besides, application of ultrasensitive analytical methods based on the studies of MGR fluorescent spectra of solutions emitting MGR revealed there traces of ••C=O and H_2N• free radicals [see the description of this method in (11)]. Thus, the hypothesis that urea and water may decompose to free radicals has been confirmed.

Generally, the same mechanism is responsible for MGR emission from other reactions of enzymatic hydrolysis (e.g., proteolysis, nucleolysis, etc.). This phenomenon has been unrecognized and is neglected until now because "side reactions" of oxygenation serving the ultimate source of energy for MGR represent such a minor part of all chemical transformations taking place in the reaction systems that their input cannot be observed using customary calorimetric approaches.

Until recently, skeptics could call in question the possibility of oxygen splitting due to two-photon excitation on irradiation of the solution with visible light. In the 1990s, such a physical phenomenon was definitely demonstrated. It was shown that under appropriate conditions even a evanescent photonic wave could cause two-photonic excitation of a fluorescent compound (12).

Another important peculiarity of proteolytic reactions leading to the emergence of MGR is water oxidation to H_2O_2 with active oxygen. Recently, it turned out that such an "unthinkable" reaction takes place in aqueous solution provided by the availability of active oxygen and specifically organized water (13, see also Voeikov, this volume). An important consequence of water oxidation accompanying hydrolytic reactions in the presence of active oxygen is that these normally thermoneutral reactions become the source of not only MGR but also of high density energy that may be stored in the form of H_2O_2 or other metastable peroxides and be used for the performance of other forms of functional work.

Glycolysis is an exception among other *in vitro* enzymatic and non-enzymatic reactions serving the source of MGR. Glycolytic reaction emitted MGR without highlighting with visible light, though the presence of oxygen was still needed. However, glycolysis unlike hydrolysis is an exothermic reaction, and oxygen may be activated in its course without external sources of energy, in particular, when glucose or other hexose split into two trioses, which tend gradually to convert into methylglyoxal (14). Methylglyoxal is one of the most active carbonyls activating oxygen especially in the presence of amine compounds (the latter should be present in the zymase preparation used by Gurwitsch to catalyze glycolysis) (15).

Hydrolytic and glycolytic reactions are the major catabolic reactions in any living organism. So if oxygen is available and the means of its activation efficiently operate, this sources of high density energy should operate in an organism permanently. Energy of electronic excitation may be used "as such" - for cell division triggering when this is needed, as energy of activation for low probability biochemical reactions; it may be degraded to lower frequency levels by fluorescent compounds, and it may also pool in cells and tissues in some peculiar and up to now not completely understood form.

4. SPECTRAL PROPERTIES OF MGR

As mentioned above, spectral analysis of MGR was accomplished by G.M. Frank soon after MGR discovery. As it can be seen in Figure 3, spectra of different enzymatic reactions *in vitro* consist of several narrow bands, and the width of some of them is as narrow as 1 nm, a feature very unusual for spectra of fluorescence recorded from aqueous solutions at room temperatures, where band widths usually reach several dozens nm. Another characteristic feature of MGR spectra is their specificity: for example, spectrum of nuclease reaction is the same, whether a nucleic acid or a phospholipid lecitin is taken as a substrate, and it has nothing in common with the spectrum of sugar fermentation. Initially Gurwitsch and co-workers interpreted these spectra as characteristic for a specific chemical or biochemical reaction, but later they understood that spectra were characteristic of some particular low molecular substances present in the reaction system, to be more precise, characteristic of specific chemical residues of these low molecular substances.

In particular, MGR spectra of phosphatase reaction is characteristic of a phosphate released from the substrate independent of a substrate nature. Indeed, addition of sodium phosphate into the reaction system where autoxidation of glycin proceeds and which is characterized with a very simple MGR spectrum results in the appearance of all the bands that are typical for a nuclease reaction. When glucose was added to a reaction system where urea was hydrolyzed with urease, the bands characteristic of glucose fermentation in addition to the bands characteristic of urease reaction appeared, while addition of urea to the reaction system where fermentation was going on resulted in enrichment of the spectrum with the bands representative for the urease reaction.

Hence, mitogenetic spectrum of reaction systems in which there go by reactions accompanied with the release of very high density quanta (e.g., λ=170 nm as in recombination of ••C=O + ••O) reflects excitation and fluorescence of simple low weight substances such as glucose and of chemical residues such as $-NH_2$, =C=O, -OH, and two forms of a peptide bond, R—CO—NH—R' and R—C(OH)=N—R'. This discovery allowed performing deep analysis of mechanisms of biochemical reactions beyond the reach of other methods, even highly sophisticated modern ones.

The very possibility to perform MGR spectral analysis of enzymatic and chemical reactions in the case when both concentrations of fluorescent compounds in solutions as well as the intensity of exciting radiation were extremely low argues that low intensity energy may propagate in aqueous solutions without dissipation for large distances. This property of water and aqueous system started to be acknowledged only recently (see Voeikov, this volume).

However, MGR spectral analysis recognizing particular substances and simple processes could be efficiently applied only to *in vitro* reaction systems or to some biological systems where catabolic processes were dominating over anabolic, such as freshly taken out blood, fresh excised tumor, and some others. In a lot of studies of complex biological tissues, MGR spectra did not reflect fluorescence of simple substances, and signified emission of some other entities. This applies to the so-called "degradation radiation".

4. DEGRADATION RADIATION AND NON-EQUILIBRIUM MOLECULAR CONSTELLATIONS

Pooling of MGR in living tissues was ascertained by Gurwitsch when he discovered a form of radiation which he somewhat awry defined as "degradation radiation". Unlike MGR releasing in the course of oxidative processes, degradation radiation arises from tissues (e.g., liver or muscle) in response to physiological stimulus or stress. For example, liver lay bare on a body of an alive mouse does not emit MGR spontaneously though all the biochemical processes giving rise to appropriate electronic excitation proceed in it. However, nearly immediately after an animal is injected with cocaine or glucose, a wave of MGR emerges. Same happens if liver is irritated with a weak electrical impulse, or mechanically disturbed, or just sprinkled with ice-cold water. Irrespective of the nature of the first irritation, a subsequent one cannot provoke a second wave of degradation radiation for a certain period of time.

Spectra of degradation MGR are very different from that of homogenous systems. For example, bands characteristic of specific fluorophores may be identified in spectra of spontaneous MGR from yeast cultures and they are relatively constant. Spectra of degradation MGR of yeast differ not only from that obtained in a resting state, but they differ significantly for different strains of yeast, they change depending on the nature of a factor inducing degradation MGR, on the physiological state of the living system, and on the state of its development.

The latter is well illustrated by A.A. Gurwitsh (16). She studied the properties of MGR of the naked baby rabbit muscle *in vivo* in different times of postnatal development. Spontaneous MGR was measured at a body temperature and degradation after the muscle was doused with cold physiological solution. Evolution of intensity of both kinds of MGR and of the spectrum of MGR are presented in Figure 4.

It can be seen that in the course of postnatal development intensity of spontaneous MGR decreases, while that of degradation MGR increases. During this period the processes related to muscle tissue functioning become progressively consolidated so that by the 15th day, intensity of degradation MGR reaches its maximum. Exactly by this time the posture and coordination of movements of an animal stabilizes, indicating that the processes related to muscle tissue functioning reached maximal interrelation. Spectrum of MGR also changes in a specific way. At the early stage of development, it looks like spectra of spontaneous MGR from systems containing many different flourophores. Later the number of spectral lines decreases, they widen, until only one wide line is left which has no correlation with known fluorophores.

All the properties of degradation MGR indicate that it differs in its origin from that of spontaneous one from homogenous systems. As already mentioned, the latter originates due to remission of energy released in reactions of radical recombination by fluorophores present in reaction systems. Properties of degradation MGR suggest that it arises due to disintegration of some preexisting objects retaining easily mobilizing energy of electronic excitation. Gurwitsch named these presumed objects "non-equilibrium molecular constellations". He supposed that they represent groups of excited macromolecules kept together

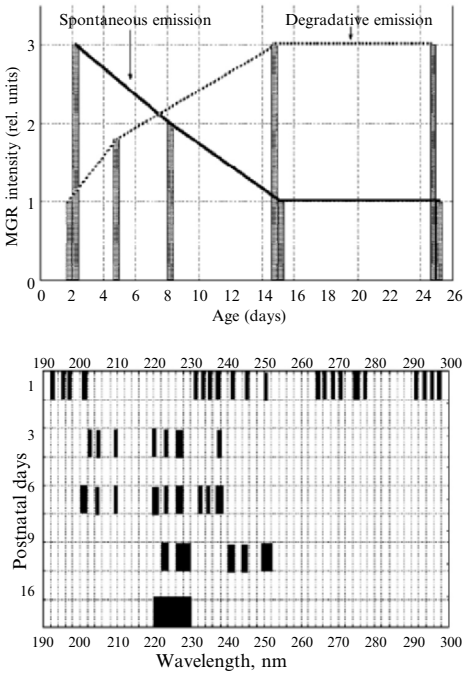

Figure 4. Top: evolution of intensity of spontaneous and degradative MGR of a baby rabbit muscle *in vivo* in different terms after birth (intensity was evaluated as a reverse of threshold period of irradiation by a muscle of yeast culture for obtaining a mitogenetic effect). Bottom: MGR spectra of a muscle (recorded at normal temperature).

due to constant energy circulation along their common energy levels. "Constellations" are fundamentally different from usual molecular associations and clusters. Components of the latter are kept together with different types of chemical bonds; energy is released when bonds lock, and sufficient energy inflow is needed for their dissociation. On the contrary, molecular constellations are sustained due to constant energy inflow, and any variations of energy supply let alone its blockade results in dispersion of constellations with release of energy retained by them. Lability of constellations precludes their revealing in fixed and even faulty biological material, and only the methods of studies of living cells and cellular systems similar to mitogenetic analysis may provide an insight of the existence of such dynamic structures.

If a constellation is disturbed by any means and loses its potential energy, the next distortion would not bring about a flash of degradation MGR until new constellations are formed. From the biological point of view, there is nothing extraordinary of such a behaviour of a constellation. Existence of refractory periods for excitable (more precise - irritable) tissues is well-known. There are many ways to trigger a nervous impulse (discharge), and until the critical value of membrane potential is restored, next irritation would not induce new impulse.

Gurwitsch applied to constellations the notion of Nobelist Albert Szent-Gyorgyi of migration of energy along the common electronic levels of protein molecules (17). But he broadened it to the possibility of migration of excitation energy along the constellations consisting of different molecules and also

considered the possibility of energy quanta summation in different localities to the levels enough to emit UV-photons. Developing this concept, he stressed that because of univocacy of energetic and spatial parameters of constellations, fluctuations in energy migration should result in spatial realignments of constellations. That is why he stated that at the molecular level of living systems "… it is wrong to oppose the notion of a structure to the notion of a process. The only correct approach to living systems is an approach to them as to the structured processes, flowing in molecular complexes widely different in the degree of their lability" (18).

The possibility of high density energy transfer to macroscopic distances has been experimentally demonstrated using mitogenetic analysis by A.A. Gurwitsch. She has shown that if one fills a narrow capillary with a dilute protein solution and expose it to MGR from one end, no emission may be registered from the opposite end under usual conditions. However, if the capillary is placed in the longitudinal (parallel to its axis) electrical field (50 v/m), it becomes a MGR conductor. Same effect is observed if the protein solution flows in a capillary at a rate of 1 m/sec. A.A. Gurwitsch supposed that this phenomenon could be explained by a thread-like form of protein molecules, and their alignment along the capillary axis under the action of electrical field or a fluid flow, that increases the probability of energy transfer from one molecule to the next one. It is interesting that the rate of photon "diffusion" in this experimental system was around 30-32 m/sec, which is very close to the rate of a nerve impulse traveling along an axon.

It also follows from this experiment that pumping of constellations with energy is a necessary but not sufficient condition of their emergence. As the elements of constellations cannot mutually orient in them due to usual chemical bonding, there should exist an external vectorial factor that imposes a certain spatial arrangement to the elements of constellations. In an example with protein solution able to conduct MGR, the role of such factor was played by an electrical field or a fluid flow.

As constellations are postulated to be the most fundamental necessary condition for the existence of living matter ("structured processes"), the uninterrupted existence of such vectorial factor of dynamic nature is also to be postulated. That is why Gurwitsch's theory of biological and cellular fields - an imprescriptible property of all living systems - cannot be considered without referring to his experimental work in "mitogenetic biology". However, Gurwitsch's theory of biological field cannot be considered here, and the reader may inquire of other sources for more information on it (19).

Thus, degradation radiation is a signature of extremely non-equilibrium state of a living tissue implying that its energy potential difference with the environment is equivalent to many thousands of degrees.

5. OBLIVION OF MITOGENETIC BIOLOGY AND ITS STEADY RECOVERY

Gurwitsch's discovery attracted much attention. In the late 1920s, he was nominated for the Nobel prize (one of those who suggested his nomination was

a world-famous physicist L.A. Mandelshtam). Many laboratories and researchers in the USSR, Germany, France, Italy, and Japan began to experiment with MGR. Mitogenetic biology reached its zenith by the middle of 1930s. From 1923 and up to 1939 hundreds of papers and a dozen comprehensive reviews on MGR appeared (for original sources see 20, 21, 22, 23). However, by the beginning of the 1940s the generally positive worldwide attitude to mitogenesis was ousted with indifference and even hostility. In 1943, Gurwitsch noted in the article devoted to the 20th anniversary of MGR discovery: "Many observers from different countries who did not dare even to try a single experiment and who are hardly acquainted with the current literature on the MGR problem, claim that the number of the works with negative results steadily grows while the number of confirming papers declines. The discrepancy of such statements with the real state of things is so striking, that if similar statements were made on ordinary, rather than scientific question, those who make them had to answer according to the law. One should just turn to the recent review by Maxia (Italy) to realize that hundreds of papers with data confirming MGR effects are opposed by less than a couple of dozens of reports with negative results"(23). However WWII destroyed all the European research centres where MGR was studied and independent works on this problem came to a halt.

In 1945, Gurwitsch founded and headed the Moscow Institute of Experimental Biology of the Academy of Medical Sciences of the USSR. In a short period of time, he and his associates managed to obtain a lot of new data. But this activity was soon interrupted. In 1948, when Lysenko regained full power in Soviet biology, Gurwitsch was dismissed. After Alexander Gawriliwich had passed away in 1954, the problem of MGR was forgotten for decades, and all his discoveries were considered to be doubtful.

At the beginning of the 1960s, Professor B.N. Tarusov and his associates at the Department of Biophysics of Moscow State University resumed studies of ultra-weak light emission from living organisms. They used photoelectronic multipliers rather than bio-tests for registering this radiation. But physical detectors still had much lower sensitivity than bio-tests. What is even more important is that most photomultipliers used register photons in much wider spectral range extending to green and even red part of the spectrum, while biological test-systems respond by mitotic reaction only to UV-photons. As it turned out photon emission in the visible range is much more intensive than in UV-range, and visible photons carry different information than UV-photons. Possibly that was the reason that the existence of Gurwitch's MGR was neither confirmed nor rejected using photomultipliers (unlike Geiger-Mueller counters used in the 1930s), though in general the ability of living systems to emit ultra-weak light discovered by Gurwitsch had been confirmed.

Professor Tarusov and his colleagues suggested that ultra-weak biological emission is the immediate result of free radical reactions, particularly of lipid peroxidation reactions and of recombination of active forms of oxygen. According to their concept, photon emission is just a by-product of such reactions, and photons do not play any significant functional role (24). This point of view is still dominant in biophysics, biochemistry, and physiology.

In the 1970s, the German physicist Friz-Albert Popp turned to the practically forgotten works of A.G. Gurwitsch (25). Using highly sensitive photoelectronic

equipment for measuring ultra-weak biological emission, he confirmed many results of the predecessors. Popp was the first to attract modern theories of quantum physics for the analysis of these results. He discovered that ultra-weak light emission of biological systems of both plant and animal origin is highly coherent in the whole range of its detection - from UV to the red part of electromagnetic wave spectrum. In other words, living systems behave as if they were lasers. However, their radiation intensity is many orders of magnitude weaker and the degree of its coherence may be many orders of magnitude higher than that of technical lasers. Besides this, biological light is intrinsically polychromatic unlike that of a laser beam.

Why do biological radiations have such properties? To answer this question Popp and his colleagues attracted quantum-physical theory of a well-known American physisist R. Dicke as well as modern theories of cavity quantum electrodynamics and of coherent electromagnetic field (26). According to Dicke's theory, two oscillators residing in the "coherent volume" of each other (this volume is calculated basing on Heisenberg's uncertainty principle, and its diameter may significantly exceed the wavelength of emitted radiation) are constantly coupled. If both oscillators are initially in an excited state, they transit into the ground one simultaneously, hence coherent radiation is emitted. Dicke's theory of radiation corresponds with that of Planck's, like Prigogine's non-reversible thermodynamics corresponds with classical thermodynamics. Cavity quantum electrodynamics is the further development of Dicke's theory. It states that if excited oscillators are in a cavity with reflecting walls, where strong coupling between oscillators and their radiation field is established, spontaneous emission by the system may be either suppressed or become highly enhanced and coherent. But how do these purely physical theories and models correspond with biological phenomena?

It is possible that coherent radiation from the whole organism reflects coherency - that is interrelationship, cooperativity of molecular constellations. They are distributed all over an organism but at the same time represent elements of the common to all of them coherent field. Organism's coherency means that an event occurring in one particular part is immediately an event for the whole organism. It has been demonstrated in Popp's laboratory that not only single organisms, but also their communities, like daphnia in a small aquarium, or seeds put in one vessel, or a yeast culture, or animal cell suspensions, behave as coherent emitters. Taking into consideration specific properties of biological electromagnetic radiation, Popp suggested for it a new term - "Biophotons".

Popp's experimental and theoretical works supported Gurwitsch's theory of "non-equillibrium molecular constellations" as of a molecular collective being in an excited state in a common for all its elements field of energy. More than that: new data and its interpretation considerably expanded this concept, since whole organisms and even their communities turned out to be similar "constellations".

Spectral analysis of biophotons made by Popp also strongly favoured and expanded Gurwitsch's theory. It turned out that there is a strong deviation of spectral distribution of biophotons from radiation of inanimate objects - the ideal example of the latter is "black body radiation". Biophoton emission intensity is in the first approximation constant within the whole range of its

detection - from UV to red light. That means that occupational probability of all energy levels - from electronic to translational ones - is practically the same, as if a living system has a tremendously high inter- and intramolecular "temperature".

Thus it is proved now that besides mitogenetic rays discovered by Gurwitsch, living organisms emit coherent and very weak light in the higher wavelength range. Gurwitsch had proved that ultraviolet photons carry out important function - they trigger cell division. And what is the function of biophotons belonging to other parts of the spectrum? There is no definite answer to this question at this time, but more and more evidence points out that they may serve for biological information transfer. Ultra-weak photon emission in the range from UV to near IR of electromagnetic spectrum from living cells and chemical reactions in aqueous media (27) affect activity of enzymes (28), activity and morphology of cells and tissues (29), regulate locomotion and mutual orientation of cultured cells (30). Back-reflected photons emitted during respiratory burst in human blood affect the intensity of this immune reaction by a feed-back mechanism (31).

Thus there are many indications that the period of oblivion of works and name of the great Russian biologist Alexander Gavrilovich Gurwitsch is passing away.

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2
PHOTON SUCKING AS AN ESSENTIAL PRINCIPLE OF BIOLOGICAL REGULATION

Fritz-Albert Popp and Wolfgang Klimek*

1. INTRODUCTION

The term *photon sucking* we understand as the *active* absorption of light. Contrary to passive absorption, this means that light becomes partially reabsorbed as soon as it is emitted or reemitted by the tissue under study. A typical example is displayed in Fig. 1.

The first observations of "photon sucking" in living tissues can be traced back to the strange phenomenon of oscillations around the relaxation curve of delayed luminescence (Popp et al., 1981). After confirmation of these findings by Chwirot et al. (1987), Schamhart and van Wijk (1987) observed some kind of photon-induced photon absorption in normal cell cultures of sufficiently high cell density, whereas this effect disappeared completely in tumor cell cultures (Fig. 2). As shown by Scholz et al. (1988), these effects are strongly correlated with the degree of coherence of the reemitted photons (Fig. 3). An even deeper understanding of this phenomenon was provided by the dissertation of M. Galle (1993). Figure 4 shows evidence of maxima and minima of biophoton emissions that were documented in populations of daphnia (and other animals), dependent on their average distances. These interference structures could be assigned to long-range interactions of the living organisms, establishing the organization of swarming, or, in more general terms, the "Gestaltbildung," of cell populations and the basis of intercellular communication. Beloussov (1997) pointed to photon sucking effects in eggshells, which behave rather differently depending on whether they are bound to their eggs or isolated. He generalized the results in case of embryonic batches of neurula stage frog embryos and loach embryos (Beloussov and Louchinskaia, 1998; Beloussov, 2002), and he established the connection to organization and communication of biological systems.

Further indications of photon sucking can be gathered from the experimental results of Vogel et al. (1998), who showed under our guidance in our laboratory that some bacteria suck up light from their nutrition medium (Fig. 5).

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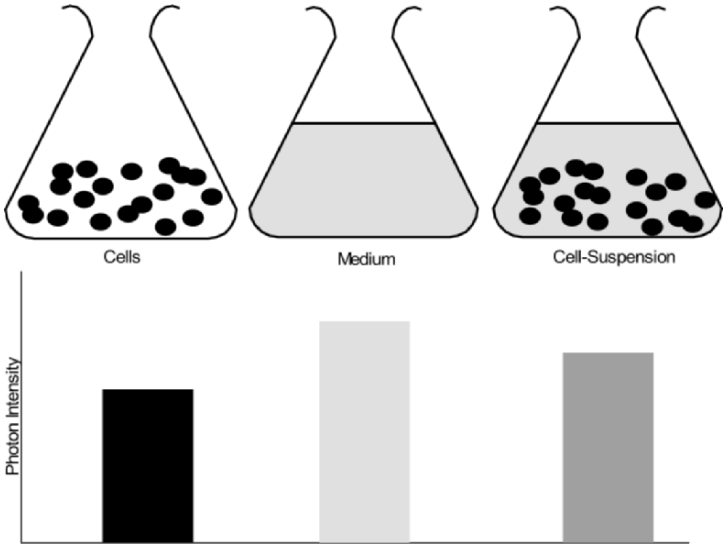

Figure 1. Cells without medium have, say, a photon emission intensity I_c. The medium shall display an intensity I_m. Both together, cells+medium, emit photons of an intensity $I < I_c+I_m$. The difference I_c+I_m-I is highly significant, indicating active absorption (sucking) of the cells within the medium.

Thus, the experimental evidence for photon sucking is already quite reliable. Therefore, the time is ripe for models of explanation, which are, however, at the present time, more or less the same, but different in the approach that is used.

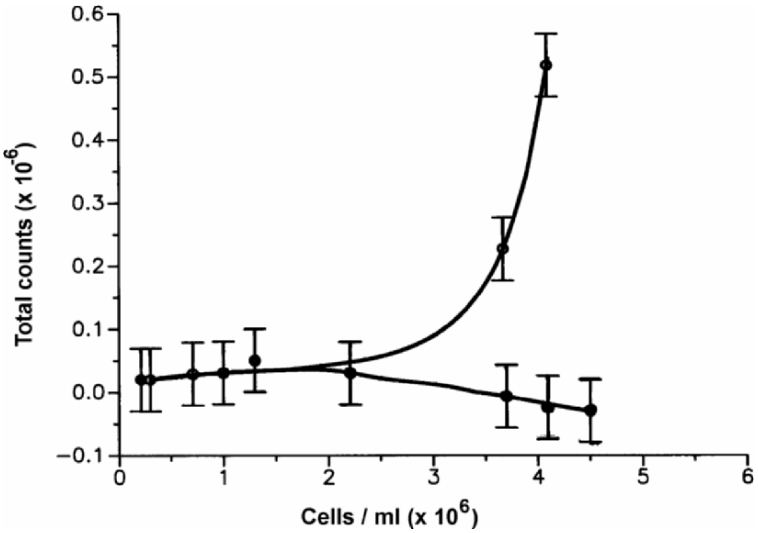

Figure 2. "Delayed luminescence" from tumor cells (upper curve) and normal cells (lower curve), as measured by Schamhart (1997). The normal cells suspended in medium display "induced absorption of photons" with increasing cell density. Tumor cells show in contrast non-linear increase of photon intensity with increasing cell density.

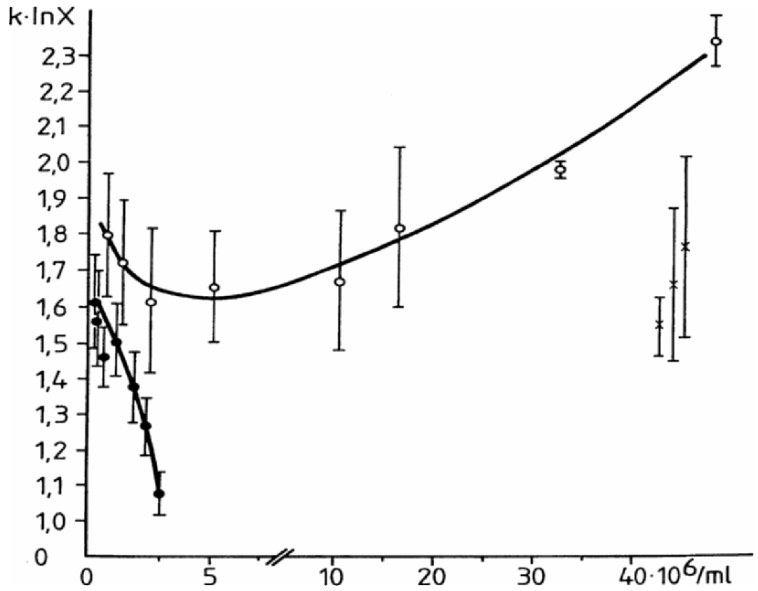

Figure 3. The decay parameter of the hyperbolic approximation that is adjusted to the relaxation dynamics of the afterglow of different cell suspensions after exposure to weak white light illumination is shown versus cell density. The lower curve displays the improvement of hyperbolic relaxation of normal amnion cells with increasing cell density. The upper curve shows the opposite dependence exhibited by malignant Wish cells. The three measurements at the right side of the figure correspond to the nutritive medium alone (Scholz et al., 1988).

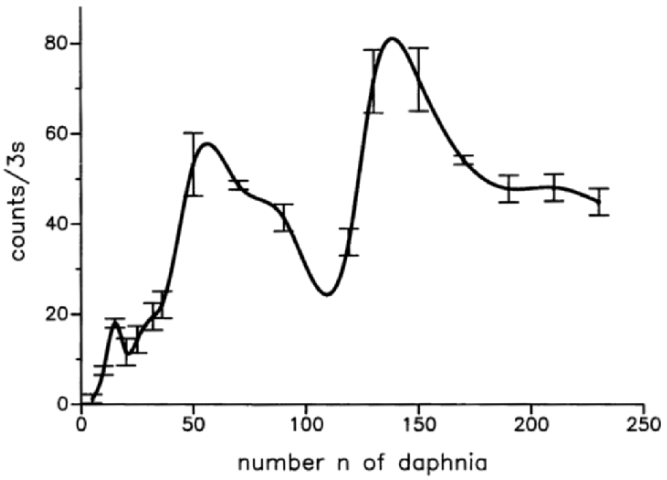

Figure 4. Mean values of the photon intensity of adolescent daphnia in 15 ml volume with the weighted standard deviation. Instead of the expected continuous increase of photon intensity with increasing number of daphnia, one measures interference-like changes (Galle, 1993).

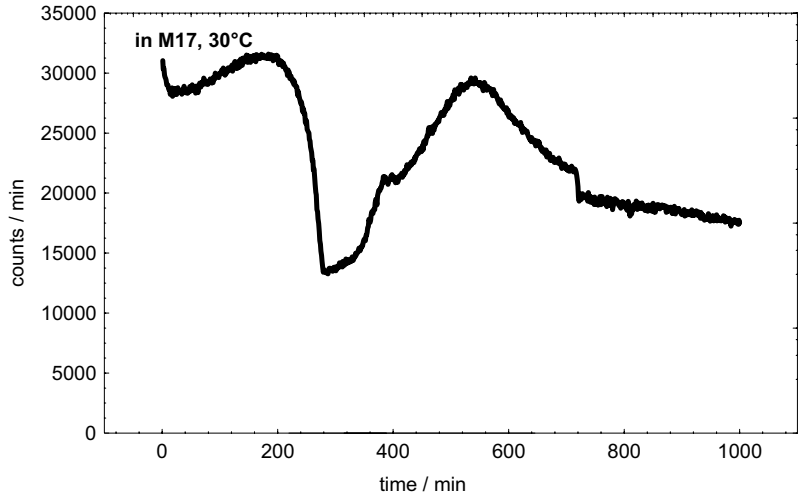

Figure 5. Growing bacteria in culture medium, that by oxidative reactions always emits light, absorb from a definite density on the light of the medium. For higher densities, this absorbance may decrease again (Vogel et al., 1998).

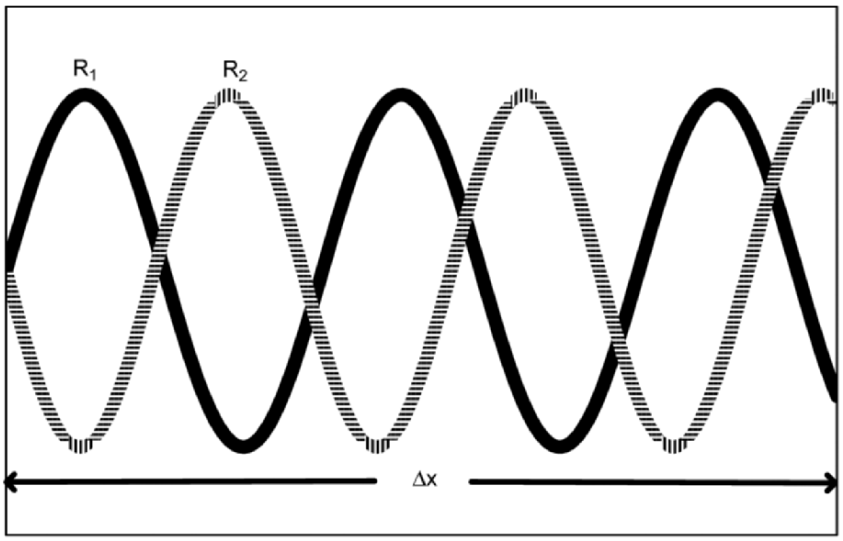

Figure 6. Zone Δx of destructive interference of two superimposing waves with different phase relations.

2. SIMPLE MODELS

Measured photons are the result of localized energy exchange of electromagnetic waves with the photon counting detector. By careful consideration using the uncertainty principle, it is never completely wrong to