Iranian Journal of Medical Physics
Vol. 12, No. 3, Summer 2015, 137-144
Received: April 15, 2015; Accepted: July 07, 2015

Review Article

Different Aspects of Ultra-weak Photon Emissions: A Review Article

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Abstract

All biological samples emit ultra-low intensity light without any external stimulation. Recently, scientific communities have paid particular attention to this phenomenon, known as ultra-weak photon emission (UPE). UPE has been introduced in the literature as an alternative for biophoton, low-level chemiluminescence and ultra-weak bioluminescence, while it differs from ordinary bioluminescence, fluorescence and phosphorescence. Some UPE parameters including spectrum and intensity have been already recognized, while other features such as the main origin(s), statistical distribution and fractality of UPE are partially understood. Ultra-weak photon detection has a broad range of potential applications in different industries such as agriculture and medicine. The correlation between UPE and physiological state of a system facilitates the use of UPE as a completely non-invasive diagnostic method in cases such as cancer detection. In this review article, we aimed to provide useful information on specific characteristics, possible origin(s) and potential applications of UPE. Moreover, we introduced some physical models for UPE and presented several controversial hypotheses in this context.

Keywords: Coherence, Statistical Distribution, Bioluminescence, Electromagnetic Radiation, Photon

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1. Introduction

Ultra-weak photon emission (UPE) is an endogenous bioluminescence phenomenon, identified in all biological samples. UPE has been also reported in non-living biological samples (e.g., vegetable oils and butter), containing oxidizable lipids or proteins [1,2]. Biological origin and spontaneous emission distinguish UPE from other types of emissions such as thermal emission, fluorescence and phosphorescence [3]. In the literature, UPE is also known as biophoton, low-level chemiluminescence and ultra-weak bioluminescence [4-7].

From a chronological perspective, Alexander Gurwitsch was the first scientist who investigated the transmission and reception of electromagnetic waves by living organisms [8,9]. He hypothesized that all cells emit ultra-weak light with an increased intensity during mitosis (cell division). He also claimed that this light can induce mitosis in other cells, as well. Consequently, he coined the term "mitogenetic radiation" [10,11].

Many claims regarding the existence of UPE and its spectral region could not be substantiated and verified until the advent of photomultiplier tubes in the 1950s [12,13]. In 1970, Popp reveled that two chemical substances, i.e., benzo[a]pyrene and benzo[e]pyrene, show different behaviors in their interaction with light [14,15]. Benzo[a]pyrene, a carcinogenic substance in cigarette smoke, absorbs light and changes its frequency, while benzo[e]pyrene, a harmless substance, passes the light without any changes. To understand this phenomenon, Popp investigated radiation from cells and coined the term "biophoton".

Several hypotheses have been proposed regarding the physical and chemical origins of UPE. From a physical perspective, any oscillating charged particle in a cell can generate an electromagnetic field, which is responsible for the consequent radiations [16]. However, reactive oxygen species (ROS), as one of the most important factors in UPE generation, result from chemical reactions during metabolic processes [16]. In this review article, we aimed to describe several hypotheses about different aspects of UPE to provide a brief summary of major works in this field.

2. Properties of UPE

Particular characteristics of UPE distinguish it from other emissions such as ordinary bioluminescence, fluorescence and phosphorescence [3]. Spontaneous emissions without pre-illumination or non-exponential decay after exposure to external light, are considered as specific properties of UPE [17].

The smooth spectral distribution of UPE, which differs from Boltzmann distribution, confirms that biological systems are far from equilibrium [18]. Ultra-weak photons are emitted in a spectral range from near-infrared to visible and near ultraviolet A. The intensity of these photons ranges from hundreds to thousands of photons per squared centimeter per second [19].

Coherence is another important feature of UPE [20,21]. In physics, a coherent state is defined as one of the states of light in which waves can interfere constructively and form interference patterns. On the other hand, coherence is sometimes considered as an equivalent to quantum behaviors, although this does not apply to all circumstances [22].

In physics, each state of light (i.e., coherent, thermal or squeezed) has a known photocount distribution (statistical distribution). Photocount distribution determines the probability of detecting different numbers of photons in a limited period of time [23-25]. According to previous research, the physiological state of a biosystem may be determined by its photocount distribution, whereas the physical state of light in which photons exist cannot be specified by photocount distribution [25].

For instance, the coherent state follows a Poisson distribution. Similarly the thermal state with many modes (degrees of freedom) has been reported to manifest Poisson distribution, as well [22]. It is evident that even photons emitted from a light-emitting diode could have Poisson distribution; therefore, photocount distribution cannot be a reliable indicator of the quantum state of light [26].

3. Possible origin(s) of UPE

All objects, either living or non-living, emit electromagnetic radiations due to thermal fluctuations of their particles. However, thermal radiations are considered to be incoherent, random and different from biological electromagnetic fields [16]. It is not surprising that many oscillating charged particles can be found in a cell. For instance, during membrane depolarization, charged particles oscillate and generate electromagnetic fields with a frequency of about 10 kHz [27 ,28].

Many protein molecules also contain electrical charge [16]. In 1968, Fröhlich claimed that electrically polar structures in biological systems contain charged particles, which vibrate coherently and generate electromagnetic fields under certain conditions [29]. His suggested model was not limited to any specific cellular structure. He also introduced a threshold above which polar structures start to vibrate non-linearly and the energy is stored in an orderly manner. He believed that this order appears as a long-range phase correlation and is analogous to superconductivity due to the collective behavior of particles. In this model, metabolic energy was introduced as the main energy supplier and the strong static electric field was known to create non-linear vibrations. Consistent with other studies, Fröhlich stated that biological electromagnetic fields affect cellular growth and can be involved in tumor development [30-33].

According to some previous studies, microtubules are another source of biological electromagnetic fields, as they meet the conditions proposed by Fröhlich [16]. Firstly, microtubules consist of tubulin heterodimers, which are electrically polar structures. Secondly, polarization and depolarization of microtubules make them dynamically unstable, resulting in the influx of energy [34]. Thirdly, the energy required for microtubule oscillations is supplied by mitochondria, which are an important source of ROS and play a significant role in UPE generation [35,36]. Also, the proposed model by Pokorný in 1997 was based on the excitations and oscillations of microtubules [37].

Popp introduced DNA as another candidate for UPE, since it consists of electrically polar structures (nucleotides), possesses luminescence properties and shows collective behaviors; therefore, it fulfills the conditions stated by Fröhlich [38]. Moreover, base stacking in DNA was claimed to provide the appropriate conditions for emissions, and DNA was considered as a photon storage system [39,40]. Therefore, when the DNA super coil unwinds (e.g., during replication), the photons are released and the intensity of emissions is increased [41]. In addition, macromolecules such as proteins and nucleic acids have been shown to possess orderly structures, which change the statistical properties of light and emit it in form of ultra-weak photon radiations [16].

In addition, as stated by Popp and Swain, high-energy photons with frequencies in THz region (visible part of the spectrum) can be generated due to energy up-conversion, which occurs under specific conditions [42]. However, no computational or experimental evidence has been provided, yet.

4. Methods for UPE detection and analysis

As stated before, the intensity of UPE is in the range of hundreds of photons per squared centimeter per second. Therefore, these emissions cannot be easily observed. To this end, low-noise photo detectors with high intrinsic electron gain and quantum efficiency are required. Up to now, photomultiplier tubes and CCD cameras have been the most commonly used devices for UPE detection and imaging [16].

The number of detected photons within a specific time interval is called photocount. By measuring the distributions of photocounts, one can obtain their statistical distributions (also known as photocount statistics). It has been stated that the structure of different photocount distributions (i.e. Poissonian, non-Possionian, etc) relates directly to the different physiological states of a biosystem emitting the UPE, such as different levels of growth. Another method called multifractal analysis has also been used to analyze UPE emissions from samples of germinating wheat seedlings. Although this method could successfully distinguish between UPEs from seedlings with different levels of intoxication, it has not repeated elsewhere so far [43].

5. Applications of UPE

It is generally accepted that UPE is proportional to metabolic activity [44]. ROS, which is the byproduct of metabolism, plays an important role in the generation of UPE [45]. In normal tissues, the generated ROS is eliminated by a defense mechanism, while the balance between generation and elimination of these species is disturbed under unhealthy conditions [45]. Relatively rapid growth of malignant tumors leads to higher metabolism, uncontrolled ROS generation and increased intensity of UPE. Therefore, it seems reasonable to define a relationship between cancer development and UPE intensity.

Many investigations have been conducted to distinguish UPE from normal and cancerous cells, although only a few in vivo studies have been conducted, so far. Consequently, detection of the relation between UPE intensity and physiological changes seems difficult [46-48]. In a study in 1998, UPE was applied to obtain further information about tumor growth, as well as resistance against anti-cancer drugs [49]. The mentioned study was the first research to detect photons from a continuous cell culture.

Based on the results, UPE intensity and cell count are closely related. Therefore, continuous measurement of UPE can be introduced as a non-invasive method for monitoring cell division and growth; also, it may facilitate distinction between different cell types. In a study in 2004, the relation between tumor size and the intensity of emissions was investigated. The results were compared with those obtained from tumor histology. Consequently, UPE was shown to be a useful source of information about tumor pathology, its activity and growth [50]. Apart from the use of UPE for medical purposes, other areas can benefit from UPE for monitoring plant responses to stress, pathogens and herbicides, as well as quality control of foods [51-54].

6. Proposed models for UPEs

The first physical model was proposed by Popp in 1976 [55]. He designed a resonance circuit, consisting of coils resembling nucleic acids and capacitors matching cell membrane (Fig. 1). This system shows a periodic response if the coupling of base pairs is neglected. On the other hand, coupling of base pairs results in the modulation of information on the periodic wave. It was claimed that this circuit has an energy of about 2-6 eV, which is matched with mitogenetic radiation.

In 1983, a model of four-level laser system was proposed for DNA emissions [32]. In this model, the so-called rate equations were reduced to a system of two equations, using Haken's "order parameter method". In 1984, another physical model for coherent emissions from DNA was proposed, which consisted of a non-linear equation with time-dependent coefficients [41]. This model could describe the dynamic behaviors of excited complexes.

Similar to the previous model, the model presented in 1988 also described DNA emissions [56]. The model was an equation for the density of emissions. Moreover, the concept of deterministic chaos was used to explain transition from a stable to an unstable state by changing the value of one of the initial conditions. Furthermore, it was claimed that a chaotic field, which follows a geometrical photocount distribution, has no correlation with physiological or biological functions, while a coherent field following a Poisson photocount distribution is correlated with physiological and biological functions.

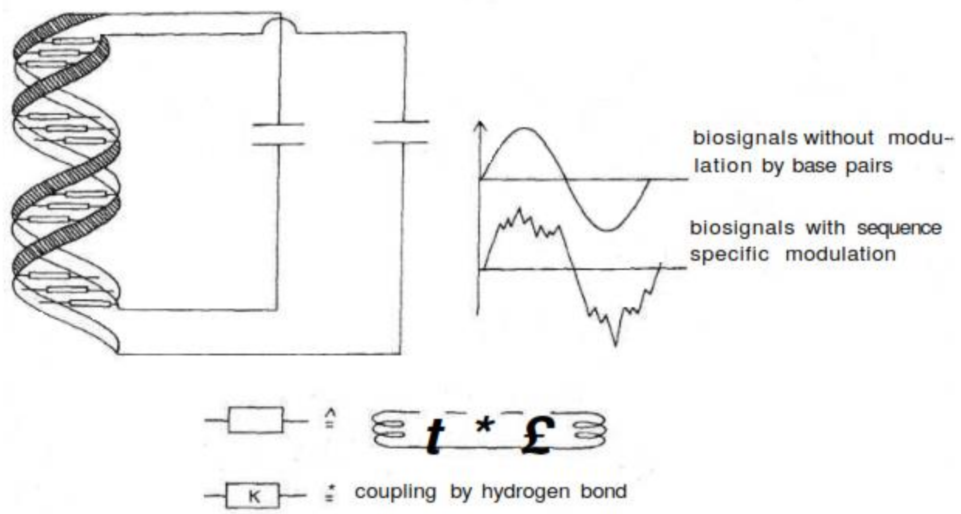

Figure 1. The resonant circuit consisting of nucleic acids as coils and membranes as capacitors

In another study in1990, Popp and Li reintroduced a four-level excimer laser model for DNA base emissions (Fig. 2) and resolved the related equations introduced in 1983 [38]. They found a system of two non-linear equations, using Haken's method and claimed that the coupled equations could not provide an exact solution. Consequently, they used the order parameter method repeatedly to reduce the equations to one non-linear equation, called the "laser equation".

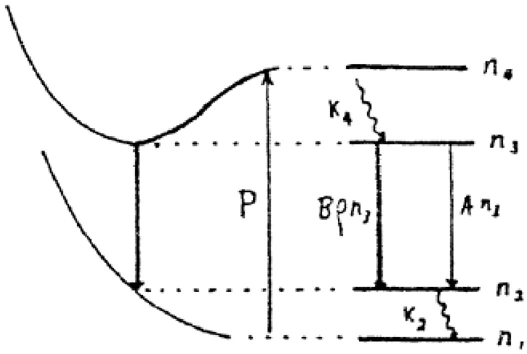

Figure 2. Four level excimer laser model for DNA base emission

7. Discussion

Although the effect of external electromagnetic fields on biological systems have been extensively investigated [57-59], endogenous ultra-weak photon emission from these systems is not well known, yet. Unambiguous evidence about the coherence of UPE, its main origin(s) and its possible role(s) seems to have been neglected in previous studies. A comprehensive theoretical model of UPE has not been proposed, either. We found that the four-level laser model of DNA emissions leads to the well-known Lotka-Volterra equations (a system of two non-linear differential equations), proposed for enzyme-substrate reactions elsewhere [60].

These equations, which can be solved using numerical methods, show periodic behaviors or limit cycles(but not chaotic response) in part of the phase plane [61]. . However, it seems that UPE and laser systems are similar in many aspects. For instance, they both are far from equilibrium and have random photon fields, which could become coherent above a certain threshold.

It seems more reasonable to claim that the photon field of an organism undergoes transitions between particular states of a chaotic field. Coherence can also be considered as one of the many states of such a chaotic field. This way, the organism could perform a more effective function, since its components sometimes need to operate individually (random state), while cooperation (coherent state) is sometimes required.

Therefore, a specific quantum state cannot be assigned to a particular physiological condition (e.g., health or disease). Instead, it can be stated that whenever the components of a biological system grow out of order, the cooperation between the subunits is lost and coherence becomes less probable. On the other hand, when all the components operate in an organized manner, the coherent state may dominate the photon field. However, to investigate coherence and other phase-related properties of UPE, interferometric measurements are required, although due to the low intensity of UPE, such measurements can be complicated [22].

Overall, UPE can be studied from different aspects including coherence theory, chaos theory and fractals [21]. Among a relatively large number of published papers on UPE, only a few include computational studies, signal analysis and detailed reports. Therefore, further research with an emphasis on signal analysis and modeling seems essential in this area.

8. Conclusion

It can be concluded that UPE is more than just a byproduct of chemical reactions or metabolic processes. The correlation between UPE intensity and physiological states suggests various potential applications of UPE. Moreover, since many fatal diseases such as cancer start from a cellular level, early diagnosis and treatment can be of great importance for the prevention of subsequent conditions. In this respect, UPE detection will be the case of interest for researchers, since it is a completely non-invasive, low-cost, real-time method.

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