IRSTI 29.31.27 https://doi.org/10.26577/RCPh97220262

A. Hagar Abdelrahman[1*], O.A.O. Gassim[2], Asma M. Elhussien[2],
I.A. Khalifa[3], Habib S. Bush[4], Mohammed Idriss Ahmed Mohammed[5],
Mubarak Dirar Abdalla[5], Yousif Shoaib Mohammed[1]
[1]Qassim University, College of Science, Department of Physics, Buraidah, Saudi Arabia
[2]Al-Baha University, Faculty of Science, Department of Physics, Al-Baha, Saudi Arabia
[3]Taif University, Al-Khurmah University College, Department of Chemistry, Taif, Saudi Arabia
[4]AL-Fayha Private College, Science and General Studies Department, Jubail, Saudi Arabia
[5]Sudan University of Science and Technology, Faculty of Science, Department of Physics, Sudan
*e-mail: a.yassin@qu.edu.sa

Unified Electromagnetic Modelling of Biophoton Propagation in Biological Media under Magnetic-Field Influence

The emission of biophotons from living systems has gained more attention due to its possible correlation with cellular metabolism, oxidative processes and physiological activities. However, the interpretation of the measured photon signals is hampered by the combined effects of optical transit, tissue characteristics and electromagnetic interactions. In this study an electromagnetic model is proposed for the description of biophoton propagation in biological medium, under the effects of attenuation, resonance effects and external magnetic fields. The technique integrates optical attenuation, electromagnetic wave propagation, magnetic-field modulation and resonance behaviour under a single theoretical framework. It is shown that the main role in defining the detectable photon intensity is played by attenuation, and under optimal conditions the behavior of the signal can be dramatically changed by magnetic-field interactions and resonance effects. The results also reveal that the detected photon signals depend on the photon generating processes as well as on the propagation conditions and the electromagnetic properties of the surrounding biological medium. The proposed paradigm gives a coherent picture of biophoton dynamics by integrating systems normally studied in isolation. Main theoretical findings agree with experimental observations. The study serves to build a conceptual bridge between biphotonic, biomedical optics and bioelectromagnetic fields. It could be helpful for future investigations to better understand measurements of photon emission and to create non-invasive optical diagnostic techniques.

Keywords: ultra-weak photon emission, tissue optics, dielectric media, photon transport, resonance behavior, bioelectromagnetic, optical diagnostics, cellular signaling.

А. Хагар Әбделрахман[1]*, О.А.О. Гассим[2], Асма М. Эльхусейн[2],
И.А. Халифа[3], Хабиб С. Буш[4], Мохаммед Ыдырыс Ахмед Мұхаммед[5],
Мубарак Дирар Абдалла[5], Юсуф Шоаиб Мұхаммед[1]
[1]Кассим университеті, Ғылым колледжі, физика кафедрасы, Бурайда, Сауд Арабиясы
[2]Әл-Баха университеті, Ғылым факультеті, физика кафедрасы, Әл-Баха, Сауд Арабиясы
[3]Таиф университеті, Әл Хурма университетінің колледжі, химия кафедрасы, Таиф, Сауд Арабиясы
[4]Әл Фейха жеке колледжі, ғылым және жалпы зерттеулер кафедрасы, Джубайл, Сауд Арабиясы
[5]Судан ғылым және технология университеті, ғылым факультеті, физика кафедрасы, Судан
*e-mail: a.yassin@qu.edu.sa

Магнит өрісінің әсерінен биологиялық ортадағы биофотондардың таралуын бірыңғай электромагниттік модельдеу

Тірі жүйелерден биофотондардың шығарылуы оның жасушалық метаболизммен, тотығу процестерімен және физиологиялық белсенділікпен ықтимал корреляциясына көбірек назар аудара бастады Дегенмен, өлшенген фотон сигналдарын түсіндіру оптикалық

транзиттің, тіндердің сипаттамаларының және электромагниттік өзара әрекеттесулердің біріккен әсерлерімен қиындайды. Бұл зерттеуде әлсіреу, резонанстық әсерлер және сыртқы магнит өрістерінің әсерінен биологиялық ортада биофотонның таралуын сипаттау үшін электромагниттік модель ұсынылады. Бұл әдіс оптикалық әлсіреуді, электромагниттік толқындардың таралуын, магнит өрісінің модуляциясын және резонанстық әрекетті бірыңғай теориялық шеңберге біріктіреді. Анықталатын фотон қарқындылығын анықтаудағы негізгі рөлді әлсіреу атқаратыны, ал оңтайлы жағдайларда сигналдың сипаты магнит өрісінің өзара әрекеттесулері мен резонанстық әсерлері арқылы түбегейлі өзгеретіні көрсетілген. Нәтижелер сонымен қатар анықталған фотон сигналдарының фотонды тудыратын процестерге, сондай-ақ таралу жағдайларына және қоршаған биологиялық ортаның электромагниттік қасиеттеріне байланысты екенін көрсетеді. Ұсынылған парадигма әдетте бөлек зерттелетін жүйелерді біріктіру арқылы биофотон динамикасының үйлесімді көрінісін береді. Негізгі теориялық тұжырымдар эксперименттік бақылаулармен сәйкес келеді. Бұл зерттеу бифотонды, биомедициналық оптика және биоэлектромагниттік өрістер арасындағы тұжырымдамалық көпір қызметін атқарады. Ол фотондардың шығарылуына өлшеулерді жақсырақ түсінуге және инвазивті емес оптикалық диагностика әдістерін жасауға арналған болашақ зерттеулер үшін пайдалы болуы мүмкін.

Түйін сөздер: өте әлсіз фотон эмиссиясы, тіндік оптика, диэлектрлік орталар, фотон тасымалы, резонанстық әрекет, биоэлектромагниттік, оптикалық диагностика, жасушалық сигнал беру.

А. Хагар Абделрахман[1]*, О.А.О. Гассим[2], Асма М. Эльхусейн[2],
И.А. Халифа[3], Хабиб С. Буш[4], Мохаммед Идрисс Ахмед Мохаммед[5],
Мубарак Дирар Абдалла[5], Юсиф Шоаиб Мохаммед[1]
[1]Университет Касима, Колледж науки, физический факультет, Бурайда, Саудовская Аравия
[2]Университет Аль-Баха, Факультет естественных наук, Аль-Баха, Саудовская Аравия
[3]Университет Таиф, университетский колледж Аль-Хурма, Таиф, Саудовская Аравия
[4]Частный колледж Аль-Фейха, Джубайль, Саудовская Аравия
[5]Университет науки и технологий Судана, факультет естественных наук, Судан
*e-mail: a.yassin@qu.edu.sa

Единое электромагнитное моделирование распространения биофотонов в биологических средах под воздействием магнитного поля

Эмиссия биофотонов из живых систем привлекает все большее внимание в связи с ее возможной корреляцией с клеточным метаболизмом, окислительными процессами и физиологической активностью. Однако интерпретация измеренных фотонных сигналов затруднена из-за комбинированного воздействия оптического переноса, характеристик тканей и электромагнитных взаимодействий. В данном исследовании предложена электромагнитная модель для описания распространения биофотонов в биологической среде под воздействием затухания, резонансных эффектов и внешних магнитных полей. Методика объединяет оптическое затухание, распространение электромагнитных волн, модуляцию магнитного поля и резонансное поведение в рамках единой теоретической модели. Показано, что основную роль в определении детектируемой интенсивности фотонов играет затухание, а в оптимальных условиях поведение сигнала может существенно изменяться под воздействием магнитных взаимодействий и резонансных эффектов. Результаты также показывают, что детектируемые фотонные сигналы зависят от процессов генерации фотонов, а также от условий распространения и электромагнитных свойств окружающей биологической среды. Предложенная парадигма дает целостную картину динамики биофотонов путем интеграции систем, обычно изучаемых изолированно. Основные теоретические выводы согласуются с экспериментальными наблюдениями. Исследование служит для построения концептуального моста между бифотонной, биомедицинской оптикой и биоэлектромагнитными полями. Оно может быть полезно для

будущих исследований, направленных на лучшее понимание измерений излучения фотонов и создание неинвазивных оптических диагностических методов.

Ключевые слова: сверхслабое излучение фотонов, тканевая оптика, диэлектрические среды, перенос фотонов, резонансное поведение, биоэлектромагнитные явления, оптическая диагностика, клеточный сигнал.

Introduction

Biophoton emission or ultra-weak photon emission (UPE) is the spontaneous emission of low intensity photons by living organisms in the absence of external visual stimulation [1–5]. Such emissions have been reported in a variety of biological systems including microbes, plants, animals and human tissues [1–5]. Biophoton emission is characterized by very low photon intensities and differs from standard bioluminescence. Biophoton emission is usually linked to metabolic activity, oxidative reactions and intracellular energy transfer pathways [1,4–7]. There is increasing evidence that biophotons may provide useful information about physiological states, cellular communication and oxidative stress dynamics [2,5].

The emission of biophotons is usually related to reactive oxygen species (ROS) and electronically excited molecular states that are formed during metabolic reactions [4,6–8]. Excited intermediates are generated through oxidative activities in mitochondria and other cellular structures, which emit photons during relaxation to lower-energy states [4,6,7]. Experimental studies have shown relationships between biophoton intensity and cell metabolism, stress circumstances, disease states, and biological aging [2,5]. These discoveries have attracted great attention in the study of the physical principles of photon generation and propagation in biological systems [1,2].

The experimental detection of biophotons has been brought to a significant advance. However, the theoretical description of the behavior of photons in biological medium is still insufficient [1]. Biological tissues are complex electromagnetic environments with varied optical properties, wavelength dependent absorption coefficients, scattering processes and dielectric responses. As a result, the photons created in living tissues interact numerous times before being detected outside, which in turn affects the measured intensity, geographical distribution and temporal features of biophoton emission [9–13].

Propagation of electromagnetic radiation in biological media has been studied extensively in biomedical optics and biophotonics. Optical attenuation is due to absorption and scattering effects related to tissue composition, cellular architecture, water content and concentrations of chromophores. The photon penetration depth and detection probability varies greatly [9–13] as the attenuation behavior is largely dependent on the wavelength and the tissue type. Therefore, it is necessary to understand these processes to interpret the experimental findings of ultra-weak photon emission and to assess their biological importance [1, 9–13].

External electromagnetic and magnetic fields affect biological systems at other organizational levels besides the optical attenuation. Previous investigations have revealed that magnetic fields may influence radical-pair dynamics, charge transport mechanisms, oxidation reactions and cellular signal transduction pathways. Such processes may affect photon-generating reactions and hence the intensity and time course of biophoton emission. Experimental data hints at possible connections between the exposure to the magnetic field and the properties of the emitted photons, but a unifying scientific approach to describe such interactions is yet missing [14-20].

Recent developments in biophotonics, photobiomodulation and bioelectromagnetics have stimulated the interest in the interaction of electromagnetic fields with living matter. All these advances point to the necessity for theoretical models that incorporate photon creation, optical transport, attenuation processes and impacts of magnetic field in a common framework. Such models may lead to a better understanding of energy-transfer processes in biological systems and to a better interpretation of experimental results described in the literature [17–24]. In contrast to earlier works that discussed biophoton emission, optical transport or magnetic-field effects separately [1,14,17], the present work unifies these processes in a single electromagnetic framework which allows for a full account of photon generation, propagation, attenuation, resonance and magnetic-field modulation behaviour in biological media.

Research Methodology

Biophoton emission is usually considered to be related to biochemical reactions with electronically excited molecular states, which are generated in the course of cellular metabolism [1–6]. In particular,

oxidative mechanisms (reactive oxygen species (ROS), lipid peroxidation and mitochondrial electron transport) can give rise to excited molecular intermediates, which could be capable of emitting photons during radiative relaxation. These ultra-weak emission phenomena are usually observed in the spectral window from the near-ultraviolet to near-infrared region.

From the electromagnetic point of view biological tissues can be considered as distributed photon emitting structures embedded in a lossy dielectric medium. Thus the observed biophoton signal is not only dependent on the mechanisms of photon generation, but also on propagation, attenuation and electromagnetic interactions in the surrounding biological environment. The overall conceptual structure of the proposed framework is given in Figure 1.

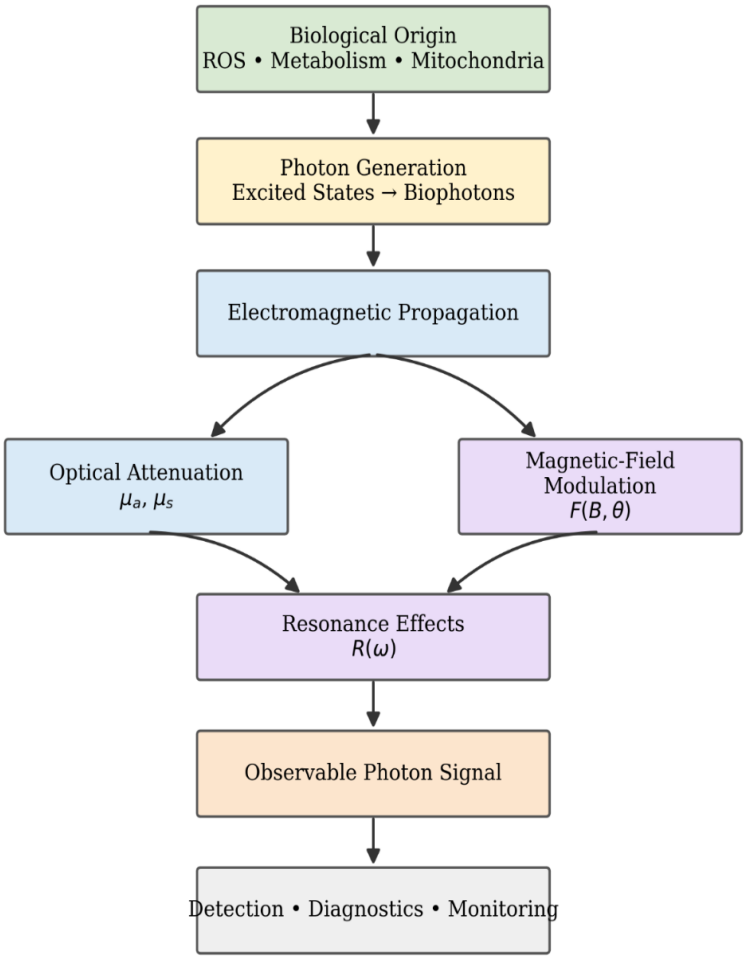

Figure 1. Unified electromagnetic framework illustrating the biological origin, generation, propagation, attenuation, magnetic-field modulation, resonance behavior, and detection of biophotons in biological media.

Fig. 1 displays the conceptual scheme of the proposed electromagnetic model for the description of biophoton dynamics in biological medium. The model assumes that biophoton emission is the consequence of oxidative metabolic activities, mitochondrial activity, and other intracellular biochemical reactions which can produce electronically excited molecular states. These excited states then serve as sources of ultra-weak photon emission.

Once formed biophotons propagate in a complicated biological medium with absorption, scattering and dielectric heterogeneity. Hence the observed photon signal is not only determined by the emission process but also by transport processes during transmission. In the proposed framework, two important elements affecting the transit of photons are considered: optical attenuation and magnetic-field modulation. Optical attenuation decreases the detected visible signal by losses through absorption

and scattering, and magnetic field interactions can modify photon-related processes via resonance-dependent mechanisms and spin-sensitive pathways.

The combined effect of propagation, attenuation, resonance and magnetic modulation ultimately defines the biophoton signal available for detection and analysis. Thus, the framework gives a coherent physical account of the relationship between biological photon generation and electromagnetic transport processes and prospective diagnostic applications.

Optical Attenuation and Absorption

Biophotons travel through biological tissue and their intensities are reduced by absorption and scattering processes in the medium surrounding the biological tissue. These effects are important for the determination of the detectable photon signal and thus affect the interpretation of experimental measurements of ultra-weak photon emission. This behavior is described by the Beer–Lambert law, which is used as a first order approximation for optical attenuation in biological media [9–13].

$$B(x) = B_0 e^{-\mu_t x} = B_0 e^{-\mu_t ct}, \tag{1}$$

where B_0 is the initial biophoton intensit, $B(x)$ is the biophoton intensity after propagating a distance x, and $\mu_t$is the effective attenuation coefficient, c is the speed of light, and t is time.

The attenuation coefficient depends on tissue composition, wavelength, water content, chromophore concentration, and cellular microstructure. Consequently, the observable biophoton signal may vary significantly among different biological tissues and physiological conditions.

The total attenuation coefficient may be expressed as

$$\mu_t = \mu_a + \mu_s, \tag{2}$$

where μ_a represents absorption and μ_s represents scattering.

The attenuation formulation adopted in this work follows the classical Beer–Lambert formalism widely used in biomedical optics and tissue–light interaction studies. Unlike conventional applications that primarily describe optical intensity decay, the present framework incorporates attenuation as an integral component of biophoton transport and magnetic-field-dependent modulation [9–13].

Electromagnetic Propagation in Biological Media

Biological tissues behave as heterogeneous dielectric media characterized by electrical conductivity, permittivity, permeability, and frequency-dependent optical properties [9–13]. Electromagnetic radiation generated within living tissues therefore interacts continuously with the surrounding biological environment.

For an isotropic medium, electromagnetic wave propagation may be described by

$$\nabla^2 E - \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0, \tag{3}$$

where E, μ, ε are the electric-field amplitude, the magnetic permeability, and the electric permittivity, respectively.

Assuming harmonic propagation, the electric field may be written as

$$E(x,t) = E_0 e^{i(kx-\omega t)}, \tag{4}$$

where E_0, k, and ω denote the field amplitude, wave number, and angular frequency, respectively.

The phase velocity is given by

$$v = \frac{1}{\sqrt{\mu\varepsilon}} \tag{5}$$

indicating that photon transport depends strongly on the electromagnetic properties of the biological medium. [11, 13, 17] In the present framework, electromagnetic propagation is considered together with attenuation effects. Consequently, the observable biophoton signal depends on the combined influence of photon generation, propagation, absorption, scattering, and medium-dependent electromagnetic characteristics. [11, 13, 17, 18]

Magnetic-Field Coupling and Resonance Effects

External magnetic fields may influence biological photon-generating processes through several mechanisms, including modulation of radical-pair reactions, charge-transport pathways, spin-dependent interactions, and resonance-related phenomena [10–14].

To describe this effect phenomenologically, the biophoton intensity under magnetic-field exposure may be expressed as

$$I_B = I_0 F(B,\theta), \tag{6}$$

where I_0 , $B, \theta, F(B,\theta)$ are the photon intensity in the absence of an external magnetic field, the magnetic flux density, the field orientation, and a magnetic modulation function, respectively. For weak magnetic perturbations,

$$F(B,\theta) = 1 + \alpha B \cos\theta, \tag{7}$$

where α characterizes the magnetic sensitivity of the biological medium.

Substituting Equation (7) into Equation (6) yields

$$I_B = I_0(1 + \alpha B \cos\theta). \quad (8)$$

Indicating that photon intensity may vary with both magnetic-field strength and orientation. Biological systems also contain oscillatory biochemical and electromagnetic processes that may exhibit resonance behaviour when external excitation conditions approach characteristic frequencies of the system. A generalized resonance response may be represented by

$$R(\omega) = \frac{R_0}{1 + \left(\frac{\omega - \omega_0}{\Gamma}\right)^2}, \quad (9)$$

where $R_0, \omega,\ \omega_0,\ \Gamma$ are the maximum resonance response, the excitation frequency, the resonance frequency, the resonance bandwidth, respectively.

To account for both resonance enhancement and attenuation effects, the observable photon intensity may be written as

$$I_{obs} = I_0 R(\omega) e^{-\mu_t x} = I_0 R(\omega) e^{-\mu_t ct}, \quad (10)$$

where μ_t is the effective attenuation coefficient.

Previous studies have frequently examined attenuation, electromagnetic propagation, magnetic-field effects, or resonance behaviour separately. In contrast, the present framework combines these mechanisms within a unified electromagnetic description, allowing the coupled influence of attenuation, propagation, resonance, and magnetic-field modulation on biophoton transport to be investigated consistently. [17,18]

Theoretical Analysis

Model Assumptions

The proposed framework is based on the biological tissues being treated as effective dielectric media, photon emission originating from intracellular biochemical reactions, optical attenuation following Beer–Lambert behaviour at the macroscopic level, magnetic-field effects represented through a phenomenological modulation term, and resonance phenomena described using a generalised Lorentz-type response function.

These assumptions enable the development of a tractable theoretical model while preserving the principal physical mechanisms that govern biophoton propagation and modulation in biological systemsInfluence of Optical Attenuation

The proposed framework demonstrates that optical attenuation is one of the dominant factors governing the observed intensity of biophoton emission in biological tissues. The biophoton intensity is attenuated exponentially during photon propagation through absorbing and scattering media by the Beer–Lambert attenuation relationship in Equation (1).

The analysis shows that small changes in attenuation coefficients could lead to large differences in the intensity of detected photons. Therefore, tissue composition, water content, chromophore concentration and structural organization are expected to have an impact on the measured distribution of ultra-weak photon emission.

Figure 2: Predicted intensity decay for representative attenuation coefficients. The higher the attenuation coefficient the faster the decline of the photon intensity and the lower the possibility of detection from the outside.

The results are consistent with recent studies on tissue optics and wavelength dependent photon transport in biological mediums [14, 17, 18]. The Beer–Lambert attenuation law implies that the photon intensity drops exponentially with the propagation of photons in absorbing and scattering material. To illustrate this tendency, numerical simulations were performed for representative attenuation coefficients corresponding to weak, moderate and strong attenuation circumstances.

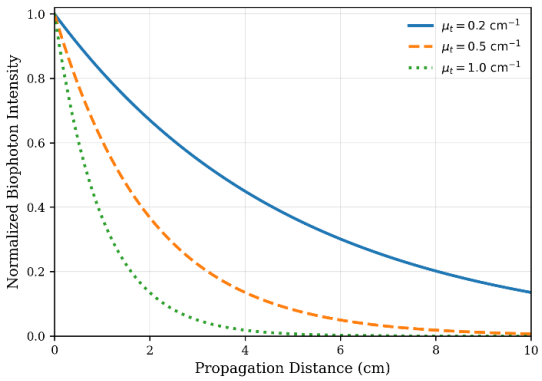

Figure 2. Simulated biophoton intensity as a function of propagation distance for various attenuation coefficients.

Figure 2 shows the significant effect of the optical attenuation on the observed biophoton signal. For low attenuation coefficients the photon intensity is detectable across longer distances of propagation. High attenuation coefficients, on the other hand, cause a quick decay of the signal, considerably limiting the possibility of external detection.

These results underscore the importance of tissue optical properties in determination of the observable parameters of ultra-weak photon emission [9-13].

Effects of Resonance and Magnetic Field

The predicted model indicates that the observable biophoton intensity could be influenced by external magnetic fields via alterations of the resonance conditions, spin-dependent interactions and energy-transfer processes.

Equation (8) shows the dependence of photon intensity on the magnetic field strength and its orientation. The response is approximately linear for weak magnetic fields, whereas stronger perturbations may cause larger deviations due to increased coupling between electromagnetic and biological processes.

The effect of the resonance also modulates photon intensity. Using the resonance function in Equation (9), the model predicts a characteristic enhancement as the excitation frequency approaches the biological system's intrinsic resonance frequency. In this case, the efficiency of energy transfer increases, and the photon signal reaches a maximum.

The observed intensity decreases gradually as the excitation frequency deviates from resonance. This behaviour is qualitatively in agreement with resonance phenomena reported in electromagnetic and biophotonic investigations [14–20].

Figure 3 highlights the competing roles of attenuation and resonance in shaping the detectable biophoton signal. While optical attenuation continuously reduces photon intensity during propagation, resonance effects may enhance signal strength under favorable conditions. The observable photon signal therefore reflects the balance between these opposing mechanisms.

The temporal evolution of biophoton intensity according to Eq.(10) is shown in Figure 4.

Combined Behaviour of the Proposed Framework

The proposed framework claims that the measurable biophoton intensity is modulated by the interplay of attenuation, resonance phenomena and magnetic field modulation. Combining Equations (1), (8), and (9), the generalized observable intensity may be represented as

$$I_{\text{obs}} = B(x)\, F(B,\theta)\, R(\omega), \qquad (11)$$

where attenuation governs photon losses, resonance contributes to signal enhancement, and magnetic-field modulation alters the overall response of the system. The theoretical predictions indicate that a solid interpretation of the biophoton measurements requires taking into account a number of interacting factors, such as tissue-specific optical properties, environmental electromagnetic conditions, magnetic field strength and orientation, and resonance characteristics of the biological system.

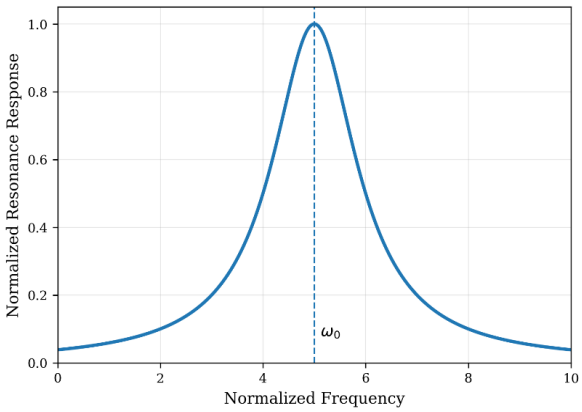

Figure 3. Simulated resonance response of the proposed electromagnetic framework.

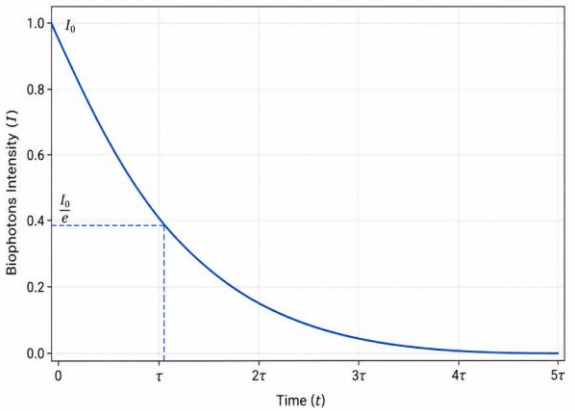

Figure 4. Time evolution of biophoton intensity according to theoretical equation 10.

Failure to take these factors into account may lead to a large variation of the experimentally observed photon intensities. The proposed framework thus offers a physically consistent basis for interpreting measurements of ultra-weak photon emission and might help in designing future experimental investigations. More generally, the model indicates that detectable biophoton signals result from the joint action of biological activity and electromagnetic transport processes. This perspective may inspire the development of non-invasive diagnostic and monitoring approaches based on biophoton detection technologies [17–20].

The conceptual balance between attenuation losses and resonance enhancement is illustrated in

Figure 5. Figure 5 highlights the competing roles of attenuation and resonance in shaping the detectable biophoton signal. While optical attenuation continuously reduces photon intensity during propagation, resonance effects may enhance signal strength under favorable conditions. The observable photon signal therefore reflects the balance between these opposing mechanisms.

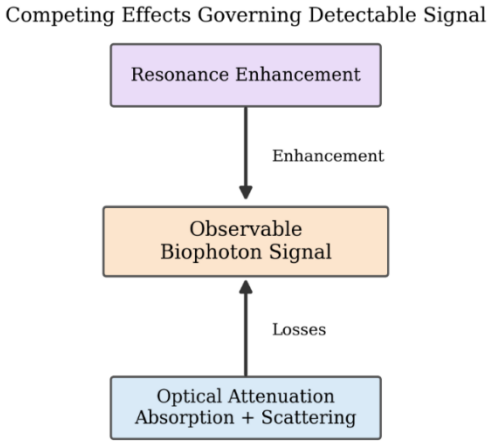

Figure 5. Competition between resonance enhancement and optical attenuation in determining the observable biophoton signal.

The number of pulses per second averaged over 1 minute for various spectral components is shown in Figure 6.

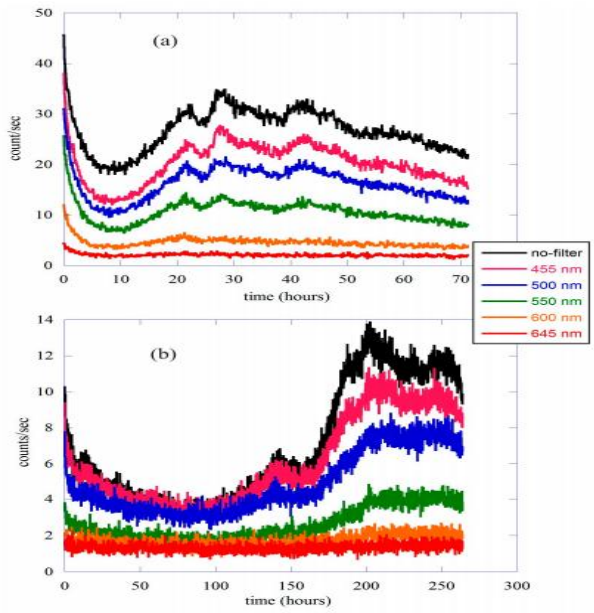

Figure 6. Counts per second averaged over 1 min for the different spectral components. Panel (a) shows exponential decay, which is related to the lentil seeds, while panel (b) refers to the single bean [27].

Figure 7 shows the exponential decay over time and the change in biophoton intensity due to the change in the attenuation coefficient caused by biotic and water stress for some randomly selected examples of the change in biophoton emission intensity over time in different experimental groups (see below for detailed results).

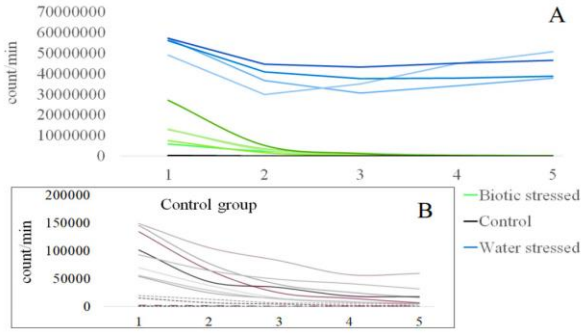

Figure 7. Exponential time decay and change in biophoton intensity due to change in attenuation coefficient. (A) Blue lines represent biophoton emission intensity of water-stressed plants; green represents plants in the biotic-stressed group; black represents measurements in the control group. (B) Dynamics of biophoton emission intensity in the control group, which is not visible in Fig. 1A due to the O (103 –104) difference in biophoton emission intensities [28].

The myogenic proliferation response to a 1.5 mT PEMF pulsed electromagnetic field directed upward and downward under light and dark conditions is shown in Figure 8. Statistical analyses were performed on at least three independent biological replicates. Data represents $n = 5$ (with three technical replicates each) independent biological replicates, and statistical analysis was performed using one-way ANOVA with multiple comparison tests, with $p < 0.01$ and $p < 0$ [29].

The theoretical predictions indicate that a reliable interpretation of biophoton measurements requires consideration of tissue-specific optical properties, environmental electromagnetic conditions, magnetic-field strength and orientation, and resonance characteristics of the biological system. The proposed framework therefore provides a physically consistent basis for interpreting ultra-weak photon emission measurements and may assist in the design of future experimental investigations. More generally, the model suggests that detectable biophoton signals arise from the combined influence of biological activity, optical transport, attenuation mechanisms, resonance phenomena, and electromagnetic-field interactions, thereby supporting the development of future non-invasive diagnostic and

monitoring approaches based on biophoton detection technologies [25, 26].

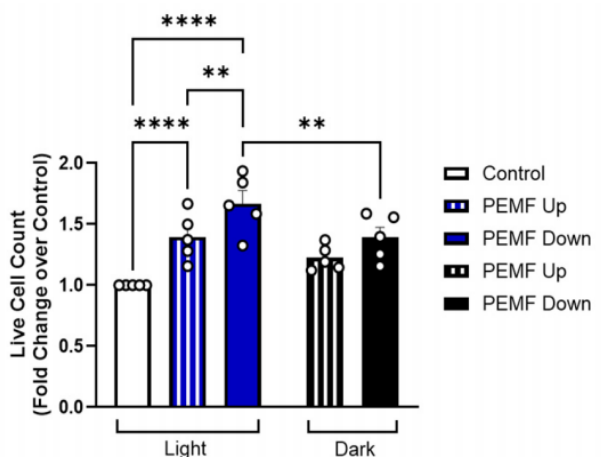

Figure 8. Myogenic proliferation in response to upward- and downward-directed 1.5 mT pulsed electromagnetic field PEMF in light and dark conditions. Live cell count of murine C2C12 myoblasts in response to upward- (lined) and downward-directed (solid) PEMF exposure in both light (in the open) (blue) and dark (black box) (black) conditions compared to the light control [29].

Table 1. Static magnetic field effects on different biological functions [30]

system		magnetic field	references
cryptochrome	cryptochrome responses enhanced	0.5 mT	Pooam *et al.*
	decrease in wing size in *Drosophila melanogaster*	35 mT	Stamenkovi-Radak *et al.*
circadian clock	circadian clock in *Drosophila melanogaster*	<0.5 mT	Yoshii *et al.*
stem cell	stem cell-mediated growth	<1 mT	Huizen *et al.*
	bone stem cells *in vitro*	0.5–30 mT	Abdolmaleki *et al.*
calcium	Ca^{2+} influx	0.6 mT	Fanelli *et al.*
	cell shape, cell surface, sugar residues, cytoskeleton and apoptosis	6 mT	Chionna *et al.*
neurons and brain	blocked sensory neuron action potentials in the somata of adult mouse	10 mT	McLean *et al.*
	symptomatic diabetic neuropathy	50 mT	Weintraub *et al.*
ROS	Increased intercellular ROS in human neuroblastoma cells	2.2 mT	Calabro *et al.*
	Increase of H_2O_2 in the human fibrosarcoma cancer cell	45−60 μT	Martino& Castello
others	flavin adenine dinucleotide photochemistry	<20 mT	Antill *et al.*
	enzymatic ATP production	80 mT	Buchachenko *et al.*

Results

Theoretical predictions suggest that a reliable interpretation of biophoton measurements requires the inclusion of a number of interacting parameters such as tissue-specific optical properties, environmental electromagnetic conditions, magnetic field strength and orientation, and the resonance features of the biological system.

Disregarding these parameters may be responsible for large range of experimentally recorded photon intensities and may confound the comparison between results obtained under different biological and environmental situations. Therefore, the suggested framework provides a physically consistent basis for the interpretation of data of ultra-weak photon emission and may be helpful in the design of future experimental investigations.

More generally, the present model proposes that the observed biophoton signals are the result of the cumulative effects of the photon creation, electromagnetic propagation, optical attenuation, resonance phenomena and magnetic field interactions. This holistic view may help in the future development of non-invasive biophotonic diagnostic and monitoring devices based on ultra-weak photon emission measurements [25,26].

Comparison with Prior Studies

This is in agreement with the experimental findings of ultraweak photon emission from biological systems and its connection with oxidative metabolic activities [1,2,4,5]. Biological photon

emission has been reported to be affected by physiological circumstances, oxidative stress, mitochondrial activity and cellular metabolism [5–8]. These findings are in agreement with the notion that biophoton emission is a quantitative expression of ongoing biochemical and bioenergetic processes in living organisms.

The attenuation part of the proposed model gives a physical explanation to the variability observed for different tissues and experimental settings. This explanation is compatible with well documented studies in tissue optics, showing that photon transport, penetration depth and signal detectability in biological mediums are highly influenced by absorption and scattering mechanisms [9–13].

In bioelectromagnetics and photobiology, biological responses based on the magnetic field have also been reported. Such reactions include regulation of spin-dependent processes, radical-pair dynamics, formation of reactive oxygen species and energy-transfer pathways [14–20]. The magnetic modulation term in the present framework provides a universal mechanism for describing such results within a unified electromagnetic description without restricting the analysis to a particular microscopic interaction mechanism.

In prior works biophoton emission, optical attenuation, electromagnetic propagation, and magnetic-field effects have been treated as independent phenomena; the present work unifies these processes in a theoretical framework. The suggested model allows a more complete understanding of the biophoton dynamics in the biological media involving photon generation, propagation and attenuation, resonance behavior, magnetic-field modulation, all in a single description [17–24].

The theoretical evolution and the effects of the attenuation coefficient and the magnetic field on the intensity stated in Eq.(10) and displayed graphically in Fig.4 are in agreement with the empirical relations displayed graphically in Figs. 6,7 and 8.

The comparison shows that the proposed framework does not substitute existing interpretations of biophoton phenomena but provides an integrative description that can link optical attenuation, electromagnetic propagation, resonance behaviour and magnetic-field modulation within one theoretical framework (Table 2).

Novel Contributions of the Present Work

The principal novel contributions of the present framework may be summarized as follows: [17–24]

1. Integration of optical attenuation and magnetic-field modulation within a single theoretical framework.
2. Unified description of biophoton propagation in biological media.
3. Capability of representing multiple interaction pathways without restricting the analysis to a specific microscopic mechanism.
4. Potential applicability to non-invasive diagnostic and therapeutic photonic technologies.
5. Agreement of the main results with the experimental observations.

Table 2. Comparison between previous biophoton studies and the proposed framework

Feature	Previous Studies	Proposed Framework
Biophoton Emission	·	·
Optical Attenuation	Partial	·
Electromagnetic Propagation	Limited	·
Magnetic-Field Effects	Partial	·
Resonance Analysis	Limited	·
Unified Theoretical Description	No	·

Biological Interpretation

From a biological perspective, the proposed model suggests that observable biophoton signals are determined not only by photon-generation processes but also by transport phenomena occurring within the surrounding biological medium.

Electronically excited states that emit ultra-weak photons are produced by cellular metabolism, oxidative processes and mitochondrial activity [6-8]. However, the signal that may be measured outside biological tissues is greatly affected by optical attenuation, scattering and electromagnetic propagation processes during photon transmission [9–13].

External magnetic fields can also affect these processes through spin-dependent interactions, radical-pair dynamics, resonance effects and energy-transfer routes [14–20]. Thus, the observed biophoton signal could arise as a consequence of a complicated interaction between the biological activity and systems of electromagnetic transport. Physiologically, differences in observed photon intensity are not always to be attributed to changes in photon production alone. Alternatively, they may also result from variations in propagation conditions, attenuation properties, resonance effects and magnetic-field-dependent transport mechanisms in biological tissue [6–8, 9–13, 14–20].This interpretation supports the view that biophoton emissions may serve as a sensitive indicator of

physiological and biochemical processes occurring within living systems.

Importance of the Proposed Framework

The main contribution of this work is the combination of many mechanisms that usually are studied separately: biophoton generation, electromagnetic propagation, optical attenuation, magnetic-field modulation and resonance behaviour. The model described here, which includes these processes in a cohesive theoretical framework, provides a physically consistent basis for the interpretation of ultra-weak photon emission in biological systems. The framework offers a conceptual relation between biophotonics, biomedical optics and bioelectromagnetics, thus providing a larger outlook for future theoretical and experimental studies.

Apart from its theoretical significance, the model could be helpful in interpreting biophoton readings from experiments, and can provide a basis for the development of future non-invasive optical diagnostic methods. The paradigm highlights the combined roles of attenuation, resonance and magnetic-field modulation in the photon transport and thus leads to a more complete understanding of ultra-weak photon emission in complex biological contexts [17–24].

Limitations and Future Directions

It is important to note several limitations of the present framework. First, the biological tissues were modelled as an effective dielectric medium, with microscopic structural complexity not considered. Second, the magnetic modulation function was introduced phenomenologically and does not attempt to describe a particular molecular or biochemical mechanism. Third, the implementation of the resonance component was simplified to capture general trends rather than detailed tissue-specific responses. Finally, the present framework offers qualitative and semi-quantitative predictions, which await further experimental validation under controlled biological and electromagnetic conditions. Future versions of the model may include tissue-specific optical parameters, nonlinear electromagnetic interactions, detailed biochemical pathways, and advanced numerical simulations. Validation through modern photon-detection techniques and controlled magnetic-field exposure systems in experiments could further improve the framework's predictive power and strengthen its applicability to biomedical investigations [20,26].

Conclusion

The emission of biophotons from living systems has attracted more and more attention due to its possible connection with cellular metabolism, oxidative processes and physiological activity. The interpretation of the measured photon signals, however, remains difficult due to the combined effects of optical transit, tissue characteristics and electromagnetic interactions. In this study, an electromagnetic model is proposed for the description of biophoton propagation in biological media, under the effects of attenuation, resonance effects and external magnetic fields. The technique integrates optical attenuation, electromagnetic wave propagation, magnetic-field modulation and resonance behaviour in a unified theoretical framework. The analysis demonstrates that attenuation is the key determinant in determining the detectable photon intensity, but magnetic-field interactions and resonance effects can considerably alter the behaviour of the signal in proper conditions. The results further indicate that the detected photon signals depend not only on the photon generating processes but also on the propagation conditions and the electromagnetic properties of the surrounding biological medium. The proposed paradigm yields a consistent understanding of biophoton dynamics by merging mechanisms that are generally investigated independently. The study contributes to the establishment of a conceptual bridge between biphotonic, biomedical optics and bioelectromagnetic fields. It may be useful for future studies to better understand measurements of photon emission and to create non-invasive optical diagnostic techniques.

Acknowledgement

The researchers would like to thank the Deanship of Graduate Studies and Scientific Research at Qassim University for financial support (QU-APC-2026).

Author Contributions

A. Hagar Abdelrahman: experimental design, data acquisition, analysis, interpretation of results, and writing of the manuscript; **O.A.O. Gassim:** Writing—review and editing; **Asma M. Elhussien:** Methodology; Validation; Formal analysis; **I.A. Khalifa:** Writing—review and editing; **Habib S. Bush:** Writing—original draft; **Mohammed Idriss Ahmed Mohammed:** Formal analysis; review and editing; **Mubarak Dirar Abdalla:** Project administration; Conceptualization; Data curation; **Yousif Shoaib Mohammed:** Methodology.

References

1. M. Cifra and P. Pospíšil, Ultra-Weak Photon Emission from Biological Samples: Definition, Mechanisms, Properties, Detection and Applications, *J. Photochem. Photobiol. B* **139**, 2–10 (2014). https://doi.org/10.1016/j.jphotobiol.2014.02.009
2. M. Benfatto, E. Pace, I. Davoli, R. Francini, F. De Matteis, A. Scordo, A. Clozza, L. De Paolis, C. Curceanu, and P. Grigolini, Biophotons: New Experimental Data and Analysis, *Entropy* **25**, 1431 (2023). https://doi.org/10.3390/e25101431
3. F.-A. Popp, Properties of Biophotons and Their Theoretical Implications, *Indian J. Exp. Biol.* **41**, 391–402 (2003).
4. P. Pospíšil, A. Prasad, and M. Rác, Role of Reactive Oxygen Species in Ultra-Weak Photon Emission in Biological Systems, *J. Photochem. Photobiol. B* **139**, 11–23 (2014). https://doi.org/10.1016/j.jphotobiol.2014.02.008
5. R. R. Mould et al., Ultra-Weak Photon Emission—A Brief Review, *Front. Physiol.* **15** (2024). https://doi.org/10.3389/fphys.2024.1348915
6. P. Pospíšil, Production of Reactive Oxygen Species by Photosystem II as a Response to Light and Environmental Stresses, *Front. Plant Sci.* **7**, 1950 (2016). https://doi.org/10.3389/fpls.2016.01950
7. P. Pospíšil, A. Prasad, and M. Rác, Mechanism of the Formation of Electronically Excited Species by Oxidative Metabolic Processes: Role of Reactive Oxygen Species, *Biomolecules* **9**, 258 (2019). https://doi.org/10.3390/biom9070258
8. H. Sies and D. P. Jones, Reactive Oxygen Species (ROS) as pleiotropic physiological signalling agents, *Nat. Rev. Mol. Cell Biol.* **21**, 363-383 (2020). https://doi.org/10.1038/s41580-020-0230-3
9. L. Finlayson, I. R. M. Barnard, L. McMillan et al., Depth Penetration of Light into Skin as a Function of Wavelength from 200 to 1000 nm, *Photochem. Photobiol.* **98**, 974–981 (2022). https://doi.org/10.1111/php.13550
10. V. V. Tuchin, Tissue Optics: Light Scattering Methods and Instruments for Medical Diagnosis, 3rd ed. (SPIE Press, Bellingham, WA, 2015).
11. S.L. Jacques, Optical Properties of Biological Tissues: A Review, *Phys. Med. Biol.* **58**, R37–R61 (2013). https://doi.org/10.1088/0031-9155/58/11/R37
12. A.N. Bashkatov, E.A. Genina, and V.V. Tuchin, Optical Properties of Skin, Subcutaneous, and Muscle Tissues: A Review, *Journal of Innovative Optical Health Sciences* **4**, 9-38. https://doi.org/10.1142/S1793545811001319
13. V.V. Tuchin, Tissue Optics and Photonics: Biological Tissue Structures [Review], *J. of Biomedical Photonics & Eng*. **1**(1), 3-21 (2015). https://doi.org/10.18287/JBPE-2015-1-1-3
14. P. J. Hore and H. Mouritsen, The Radical-Pair Mechanism of Magnetoreception, *Annu. Rev. Biophys*. **45**, 299–344 (2016). https://doi.org/10.1146/annurev-biophys-032116-094545
15. R. Usselman, E. D. Hill, D. J. Singel, and P. J. Hore, Spin Biochemistry Modulates Reactive Oxygen Species Production, *Sci. Rep.* **4**, 7083 (2014). https://doi.org/10.1038/srep07083
16. H. Tian et al., System-Level Biological Effects of Extremely Low-Frequency Electromagnetic Fields, *Front. Neurosci.* **17** (2023). https://doi.org/10.3389/fnins.2023.1247021
17. Haiying Wang, Weijin Zou, Yi Cao, Bioelectromagnetic fields as signaling currents of life, *Radiation Medicine and Protection* **6**(2), 112-118 (2025). https://doi.org/10.1016/j.radmp.2024.09.001
18. N. Rouleau, B.T. Dotta, Electromagnetic fields as structure-function zeitgebers in biological systems: environmental orchestrations of morphogenesis and consciousness, *Front. Integr. Neurosci.* **8** (2014). https://doi.org/10.3389/fnint.2014.00084
19. A. Franco-Obregon et al., The Developmental Implications of Muscle-Targeted Magnetic Mitohormesis: A Human Health and Longevity Perspective, *Bioengineering* **10**(8), 956 (2023). https://doi.org/10.3390/bioengineering10080956
20. J.N. Iversen, Y.K. Tai, K. Y. Wu, C. J. K. Wong, H. Y. Lim, and A. Franco-Obregón, Magnetically Stimulated Myogenesis Recruits a CRY2–TRPC1 Photosensitive Signaling Axis, *Cells* **14**, 231 (2025) https://doi.org/10.3390/cells14030231
21. M.R. Hamblin, Mechanisms and Applications of the Anti-Inflammatory Effects of Photobiomodulation, *AIMS Biophys.* **4**, 337–361 (2017). https://doi.org/10.3934/biophy.2017.3.337
22. M.R. Hamblin, Photobiomodulation or low-level laser therapy, *J Biophotonics* **9**(11-12), 1122–1124 (2016). https://doi.org/10.1002/jbio.201670113
23. P. R. Arany, Photobiomodulation therapy, *JADA Foundational Science* **4**, 100045 (2025). https://doi.org/10.1016/j.jfscie.2025.100045
24. R. Zein, W. Selting, M.R. Hamblin, Review of light parameters and photobiomodulation efficacy: dive into complexity, *J Biomed Opt. 23*(12), 1-17 (2018). https://doi.org/10.1117/1.JBIO.23.12.120901
25. R.C. Burgos et al., Ultra-Weak Photon Emission as a Dynamic Tool for Monitoring Oxidative Stress Metabolism, *Sci. Rep.* **7** 1229 (2017). https://doi.org/10.1038/s41598-017-01229-x
26. L. De Paolis et al., First Experimental Measurements of Biophotons from Astrocytes and Glioblastoma Cell Cultures, *Entropy* **28**(1), 112 (2026). https://doi.org/10.3390/e28010112

27. M. Benfatto, E. Pace, I. Davoli, R. Francini, F. De Matteis, A. Scordo, A. Clozza, L. De Paolis, Catalina Curceanu, and Paolo Grigolini, Biophotons: New Experimental Data and Analysis, *Entropy* **25**(10), 1431 (2023). http://doi.org/10.3390/e25101431

28. Z. Pónya & K. Somfalvi-Tóth, Modelling biophoton emission kinetics based on the initial intensity value in Helianthus annuus plants exposed to different types of stress, *Sientific Reports* **12**, 2317 (2022). https://doi.org/10.1038/s41598-022-06323-3

29. J.N. Iversen, Y.K. Tai, K.Y. Wu, C.J.K. Wong, H.Y. Lim, A. Franco-Obregón, Magnetically Stimulated Myogenesis Recruits a CRY2-TRPC1 Photosensitive Signaling Axis. *Cells* **14**, 231 (2025). https://doi.org/10.3390/cells14030231

H. Zadeh-Haghighi and C. Simon, Magnetic field effects in biology from the perspective of radical pair mechanism, *J R Soc Interface* **19**(193), 20220325 (2022). https://doi.org/10.1098/rsif.2022.0325

Information about the Authors:

A. Hagar Abdelrahman (corresponding author) – Assistant Professor in the Department of Physics, College of Science, Qassim University, (Buraidah, Saudi Arabia, e-mail: a.yassin@qu.edu.sa).

O.A.O. Gassim – Al-Baha University- Faculty of Science- Department of Physics, (Buraidah, Saudi Arabia, e-mail: omerrassikh14@hotmail.com).

Asma M. Elhussien Al-Baha University, Faculty of Science, Physics Department, (Saudi Arabia, e-mail: asmmoh85@gmail.com).

I.A. Khalifa – Department of Chemistry, Al Khurmah University College, Taif University, (Taif, Saudi Arabia, e-mail: i.khalifa@tu.edu.sa).

Habib S. Bush – Science and General Studies Department, AL-Fayha Private College, (Jubail, Saudi Arabia, e-mail: habib.J@fayha.edu.sa).

Mohammed Idriss Ahmed Mohammed – Department of Physics, Faculty of Science, Sudan University of Science and Technology, (Sudan, e-mail: garaof@yahoo.com).

Mubarak Dirar Abdalla – Department of Physics, Faculty of Science, Sudan University of Science and Technology, (Sudan, e-mail: mubarakdirar@gmail.com).

Yousif Shoaib Mohammed – Department of Physics, College of Science, Qassim University, (Buraidah, Saudi Arabia, e-mail: ys.idris@qu.edu.sa).

Авторлар туралы мәлімет:

А. Хагар Әбделрахман (автор-корреспондент) – физика кафедрасының асс.профессоры, Ғылым колледжі, Қасым университеті, (Бурайда, Сауд Арабиясы, , e-mail: a.yassin@qu.edu.sa).

О.А.О. Гассим - Әл-Баха университеті, ғылым факультеті, физика кафедрасы (Бурайда, Сауд Арабиясы, e-mail: omerrassikh14@hotmail.com).

Асма М. Эльхуссейн, Әл-Баха университеті, ғылым факультеті, физика кафедрасы (Сауд Арабиясы, e-mail: asmmoh85@gmail.com).

И.А. Халифа - химия кафедрасы, Әл-Хурма университеті колледжі, Таиф университеті (Таиф, Сауд Арабиясы, e-mail: i.khalifa@tu.edu.sa).

Хабиб С. Буш – ғылым және жалпы білім беру факультеті, Әл-Файха жеке колледжі (Джубайл, Сауд Арабиясы, e-mail: habib.J@fayha.edu.sa).

Мохаммед Ыдырыс Ахмед Мұхаммед – физика кафедрасы, ғылым факультеті, Судан ғылым және технология университеті (Судан, e-mail: garaof@yahoo.com).

Мубарак Дирар Абдалла – физика кафедрасы, ғылым факультеті, Судан ғылым және технология университеті (Судан, e-mail: mubarakdirar@gmail.com).

Юсиф Шоайб Мұхаммед – физика кафедрасы, ғылым факультеті, Қасим университеті (Бурайда, Сауд Арабиясы, e-mail: ys.idris@qu.edu.sa).

Сведения об авторах:

А. Хагар Абделрахман (автор-корреспондент) – кафедра физики, Колледж науки, университет Кассим (Бурайда, Саудовская Аравия, e-mail: a.yassin@qu.edu.sa).

О.А.О. Гассим – университет Аль-Баха, факультет естественных наук, кафедра физики (Бурайда, Саудовская Аравия, e-mail: omerrassikh14@hotmail.com).

Асма М. Эльхуссейн, университет Аль-Баха, факультет естественных наук, кафедра физики (Саудовская Аравия, e-mail: asmmoh85@gmail.com).

И.А. Халифа – кафедра химии, университетский колледж Аль-Хурма, университет Таифа (Таиф, Саудовская Аравия, e-mail: i.khalifa@tu.edu.sa).

Хабиб С. Буш – факультет естественных и общеобразовательных наук, частный колледж Аль-Файха (Джубайль, Саудовская Аравия, e-mail: habib.J@fayha.edu.sa).

Мохаммед Идрисс Ахмед Мохаммед – кафедра физики, факультет естественных наук, университет науки и технологий Судана (Судан, e-mail: garaof@yahoo.com).

Мубарак Дирар Абдалла – кафедра физики, факультет естественных наук, университет науки и технологий Судана (Судан, e-mail: mubarakdirar@gmail.com).

Юсиф Шоайб Мохаммед – кафедра физики, факультет естественных наук, университет Кассим (Бурайда, Саудовская Аравия, e-mail: ys.idris@qu.edu.sa).

Article history: *received: 21 June 2026; revised: 23 August; accepted: 25 August 2026.*

Мақала тарихы: *түсті: 21 маусым 2026; түзетілді: 23 тамыз; қабылданды: 25 тамыз 2026.*

История статьи: *поступила: 21 июня 2026; после доработки: 23 августа; принята: 25 тамыз 2026.*