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Review

Human Bioelectromagnetism and the Environment: Introduction to the Problem

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Featured Application

The perspective piece should strengthen the transdisciplinary dialogue among scientists on further study of the interaction between the electromagnetic fields of the human body and the external environment.

Abstract

(1) Background: The increasing contribution of anthropogenic electromagnetic radiation has altered the Earth's electromagnetic landscape and poses a serious problem for electromagnetic ecology and medicine. The aim of this study was to develop a working theoretical framework to describe the current state of interaction between the human body and electromagnetic fields in the external environment and to facilitate transdisciplinary collaboration among scientists in studying and addressing this problem. (2) Methods: Extensive research has been conducted in the literature to provide a comprehensive presentation of data, enabling a working concept of the interaction between the human body and electromagnetic fields in the external environment. (3) Results: General data, theoretical foundations, mechanisms, and results of the interaction of external electromagnetic fields with the human body were presented. (4) Conclusions: There is a proven interaction between the human body and external electromagnetic fields, as the body is part of the Earth's electromagnetic landscape and has biophysical mechanisms for coupling with it. The increase in anthropogenic electromagnetic radiation is an electromagnetic environmental problem, and this requires further study of the safety issues and the impact of anthropogenic electromagnetic fields on the human body, and a reassessment of their biological impact on the human body, tightening the standards and requirements for electromagnetic safety in places where people live, a moratorium on further deployment of 5G, urgent application of the precautionary principle, and stricter exposure limits, especially for Wireless Communication Electromagnetic Fields.

Keywords: electromagnetic fields; electromagnetic ecology; anthropogenic electromagnetic radiation; DNA damage; biophoton signaling

Academic Editors: Dimitrios Nikolopoulos and Atsushi Mase

Received: 9 February 2026
Revised: 31 March 2026
Accepted: 3 April 2026
Published: 8 April 2026

1. Introduction

The current state of research into human and environmental bioelectromagnetism is incomplete. This is because the scientific consensus remains divided: many studies

show adverse effects of non-ionizing electromagnetic fields on biological organisms and humans, while others report no significant harm, underscoring the urgent need for more standardized, high-quality research. Since the health of humans and other biological organisms depends on the accuracy of future scientific conclusions, this issue undoubtedly concerns scientists across the academic community.

Therefore, studying the interactions between electromagnetic fields within the human body and the external environment is relevant to modern fundamental science. This is justified for several reasons.

The first reason is that modern fundamental science has grasped the essence of the microscopic organization of matter and recognized that electromagnetic energy underlies its structure. According to the Standard Model, all matter at the subatomic level is formed by energy in various forms [1–3]. Therefore, on the one hand, the human body has a complex electromagnetic organization and can be represented in a frequency-wave model of its structure [4]. On the other hand, electromagnetic energy and processes in biological cells underlie the phenomenon of biological life in the human body [4]. The life of each biological cell is determined by and exists due to the generation of electromagnetic energy by its membrane structures [5,6]. The action potentials of biological cell membranes in vivo are associated with cellular electromagnetic fields and also shape the movement of electromagnetic currents in the organs of the human body. Classic examples of this include the electrical conduction system of the heart [7] and the nervous system [8,9]. The cessation of the generation and circulation of electromagnetic currents in the organs and in the human body leads to death [10]. All cells of the human body use electromagnetic energy as an energy source and for the transmission of information [11–14]. Since the functioning body of a living person is a complexly organized system of electromagnetic processes, it must obey the universal laws of physics and have mechanisms for interaction with the electromagnetic fields of the external environment in accordance with the Theory of the Electromagnetic Field [15,16], the laws of electrodynamics [17], and so on. Therefore, the structures of the electromagnetic fields of atoms, molecules, cells, and organs of the human body must respond by altering their quantum-mechanical characteristics in response to changes in the parameters of the external electromagnetic field acting on them. This is an important theoretical foundation that substantiates the existence of interaction between the electromagnetic fields of the human body and the external environment. This scientific fact exists, and its study must continue to advance fundamental knowledge. This is a fundamentally important reason for studying the interactions between the body's electromagnetic fields and the external environment.

The second reason is that our human civilization has made significant progress in the study and practical use of electromagnetic energy over the past hundred years [18,19]. The exploitation of electromagnetic energy forms the foundation of our civilization. Electromagnetic energy is actively used in production and is ubiquitous in human everyday life. It is well known that electrical cables, electrical appliances, and cellular and mobile phone devices generate electromagnetic fields of varying intensity and density. This is undoubtedly an anthropogenic electromagnetic change in the natural human environment. The impact of these electromagnetic influences on the human body must also be studied. The significant increase in the number of anthropogenic electromagnetic radiation sources in recent decades underscores the relevance of research in this area and makes it simply vital.

Despite significant scientific and technological progress and associated advances in medicine, the prevalence and mortality from chronic non-communicable diseases (NCDs) continue to rise [20–23]. An increase in disorders in the sphere of mental and psycho-emotional health of people in all age groups is noted [24,25]. As noted earlier, electro-

magnetic processes underlie metabolic processes in the human body [4]. They underlie non-chemical and chemical communication between cells [11,25–27]. Higher nervous activity in a person is associated with electromagnetic processes in their body, and, first of all, with electromagnetic generation in their brain [28]. Clinical manifestations of diseases of internal organs are disturbances in the electromagnetic parameters of organ functioning. This is the basis for the use of electrography (for example, electroencephalography and electrocardiography) and magnetography (for example, magnetoencephalography and magnetocardiography) for diagnostic and scientific research purposes [29,30]. On the one hand, this testifies to the important role that electromagnetic processes of cellular functioning play in human health. On the other hand, this suggests that increased anthropogenic electromagnetic influence may be an additional pathogenetic factor in the occurrence and progression of chronic diseases of internal organs [31–40]. Therefore, the third reason why it is necessary to update the study of the interaction between the electromagnetic fields of the human body and the external environment is rooted in this.

Electromagnetic energy can be an "enemy" of human health, but it can also be its "friend". Given modern knowledge of the role of electromagnetic processes in the functioning of the human body, the use of electromagnetic energy with specific parameters can be an effective tool for treating and preventing human diseases. There are many studies on the positive therapeutic effects of electromagnetic energy with specific parameters on the human body [29]. There is data on the development of new scientific fields based on the use of electromagnetic energy for improving human health. For example, Bioelectronic Medicine, a promising scientific field at present, continues to study the mechanisms and practical applications of electromagnetic energy for therapeutic purposes [29,41–45]. The possibility of intentionally using electromagnetic energy to treat diseases and the artificial creation of electromagnetic fields with a positive effect on the human body are additional reasons why it is necessary to continue studying this. To this end, it is necessary to foster a broad interest in this area of research among as many scientists as possible. All this complementary knowledge is important for modern systems medicine, aiming to further integrate it into the unified medical science and current scientific understanding of human beings. This knowledge can significantly complement the fundamental principles of the functioning of all life on planet Earth.

This "perspective pie" was prepared to illuminate the general concept of the problem for better understanding by scientists from various fields, to promote their interest in the problem, and to facilitate future interdisciplinary collaboration in its solution. Therefore, to enhance transdisciplinary dialogue among scientists on the further study of the interaction of electromagnetic fields in the human body and the external environment, this review presents the results of a theoretical study that conceptualizes existing knowledge in the fields of human and environmental biomagnetism. The aim of the study was to develop a working theoretical framework to describe the current state of interaction between the human body and electromagnetic fields in the external environment from a systems biology perspective. The objectives were to analyze, summarize, and present existing knowledge about the formation and role of electromagnetic parameters on planet Earth, about the biomagnetism of the human body, about the mechanisms and effects of the interaction of electromagnetic processes in the human body with external electromagnetic processes in the environment, and to identify the main problems and prospects for further research.

2. Materials and Methods

General scientific methods of theoretical research were employed, including dismembering and recombining parts of the system under study, mental experience, logical and historical research, analysis, induction, deduction, and the synthesis of knowledge. Theo-

retical methods of theory construction were used: ascent from the abstract to the concrete, generalization and abstraction, axiomatic, hypothetico-deductive, logical (rules of inference, formation of complex concepts from simple ones, establishment of the truth of complex statements, principles of formation of axiomatic theories, criteria for consistency, completeness and independence of systems of axioms and hypotheses) methods and normative rules. Extensive research has been carried out in the literature to elucidate the aspects and mechanisms of interaction between the human body and the external electromagnetic radiation sources (natural and anthropogenic). The theoretical study was carried out by a transdisciplinary international team of scientists. The scientific team included biophysicists and medical scientists of various specialties.

During the study, a literature review was conducted of scientific studies published in the 20th and 21st centuries. Literary data from the scientometric databases Scopus (Elsevier), Web of Science (Clarivate), Google Scholar, and PubMed were analyzed. The selection was carried out in accordance with the stated objectives across four main topics: the formation and role of electromagnetic parameters on planet Earth; the biomagnetism of the human body; the mechanisms and effects of the interaction of electromagnetic processes in the human body with external electromagnetic processes in the environment; and the main problems and prospects for further research. To present the scientific results, a "perspective piece" was chosen as a review format that allows for an adequate presentation of the concept of knowledge on the problem.

3. Results

The concepts behind the results of the theoretical study are described as sections of the literature review. The presented sections summarize existing scientific knowledge into concepts. The graphological structure of the presentation of results is shown in Figure 1.

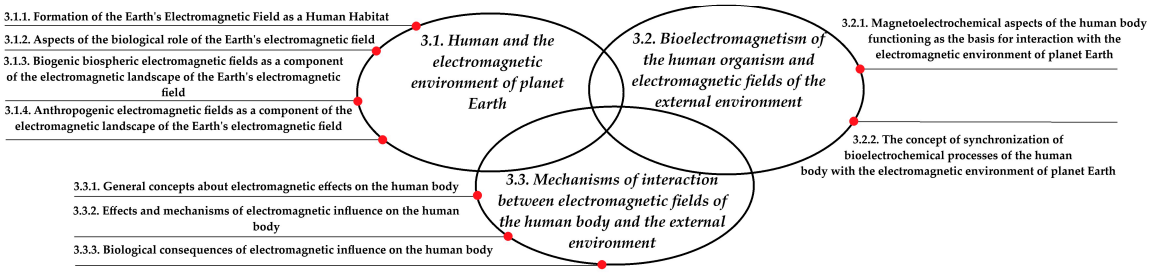

Figure 1. Graphological structure for presenting existing scientific knowledge about "Human Bioelectromagnetism and the Environment".

3.1. Human and the Electromagnetic Environment of Planet Earth

As a result of the systematization of modern knowledge, several provisions were formulated about the natural electromagnetic environment of planet Earth [46,47]: (1) It is a single, integral, omnipresent materially existing formation, represented by the matter/energy of the electromagnetic field, which has different physical characteristics in its different planetary locations. (2) It is formed according to the general laws of physics and is characterized by the presence of energy and current sources, a conducting medium, channels for wave propagation and charge separation. (3) It is of key importance for the exchange of energy at the planetary level and for ensuring the existence of the phenomenon of biological life on planet Earth. (4) It has a complex organization and continues to be studied by modern science.

The electromagnetic environment of planet Earth is formed by the fusion/interaction of such electromagnetic fields as (Figure 2): (1) the geomagnetic field [48,49]; (2) electromagnetic fields of the atmosphere of planet Earth (for example, electromagnetic fields of

local thunderstorm activity, air ionization due to corona discharges, solar radiation, resonance phenomena, etc.) [49–51]; (3) electromagnetic fields of the biosphere (for example, electromagnetic fields of all living biological organisms from prions, viruses, bacteria to plants, fungi, animals, humans) [46,49]; (4) electromagnetic fields of aquatic environments of planet Earth [46,47]; (5) electromagnetic fields of technogenic anthropogenic origin [52].

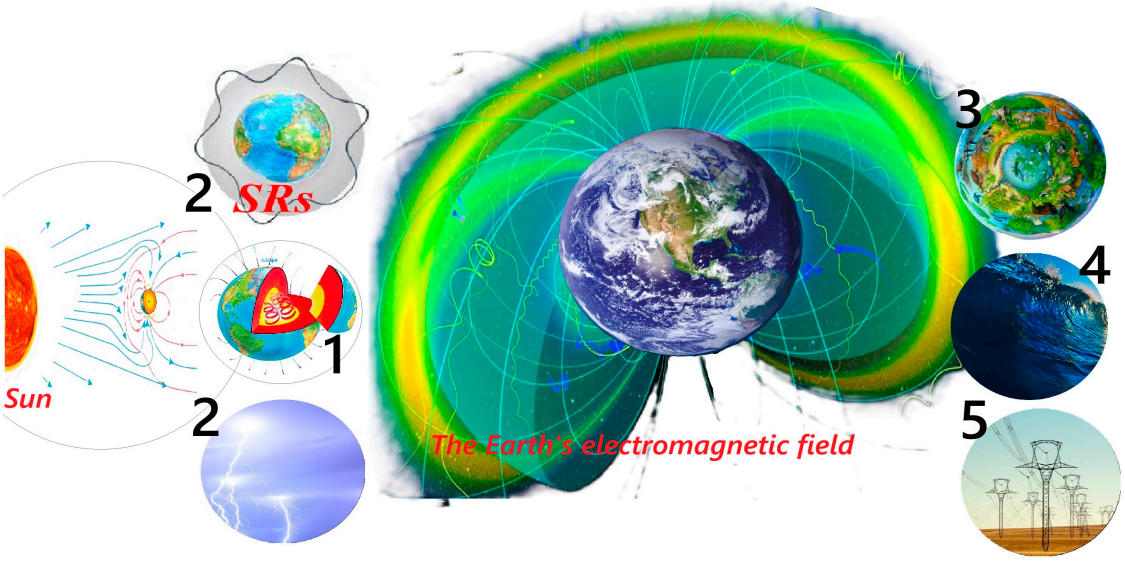

Figure 2. The primary sources of the Earth's electromagnetic field. Note: 1—Earth's geomagnetic field; 2—electromagnetic fields of the Earth's atmosphere; 3—electromagnetic fields of the Earth's biosphere; 4—electromagnetic fields of the Earth's aquatic environments; 5—electromagnetic fields of artificial anthropogenic origin.

The electromagnetic environment of the Earth's surface is called the electromagnetic landscape. This concept is crucial for systems medicine because the Earth's surface is the human habitat, and the combined physical parameters of its local electromagnetic fields influence human health [46,47,53–55].

3.1.1. Formation of the Earth's Electromagnetic Field as a Human Habitat

The electromagnetic landscape as a human habitat varies in physical parameters across different areas of Earth's surface, but the basic principles of its organization are universal. The universal natural mechanisms for the emergence of the electromagnetic landscape of Earth's surface are based on the peculiarities of its planetary structure: from a physics perspective, it represents a gigantic spherical "Earth-ionosphere capacitor." This is because the Earth has an atmosphere and a unique planetary structure, with a molten core. Because of this, the Earth's surface has high electrical conductivity and a negative charge, while the ionized, electrically conductive upper atmosphere is positively charged relative to the Earth's surface. Because the Earth's surface (a conductor) and the upper atmosphere/ionosphere (a conductor) are oppositely charged, and the lower atmosphere (a dielectric) lies between them, a unique system is formed that permanently retains an electrical charge [46,47,56,57]. Therefore, people are constantly in a natural electric field that exists between the negatively charged Earth and the positively charged atmosphere. Between the Earth's surface and the ionosphere, there is a constant difference in electrical potentials of about 300,000–400,000 volts [58–60]. The human body is a relatively good conductor [10]. This causes the human body to absorb the Earth's electrical potential and acquire a negative charge. On average, the electric field strength at the Earth's surface is approximately 100 volts per meter (V/m), although it can vary [61,62]. This means that a potential difference of several hundred volts can exist between a person's head and feet,

provided that the person is standing in the open. The electric field rearranges itself around the body, and a person does not feel any noticeable current flowing in everyday life [63].

Today, it is a categorically indisputable fact that the Earth's electromagnetic field is an important and necessary environmental condition for the existence of biological life [46,47,64,65]. In fundamental science, it is commonly referred to as the natural electromagnetic background or electromagnetic noise [46,47]. The Earth's electromagnetic field is an omnipresent physical aspect. External natural electromagnetic fields consist of electric and magnetic force fields created by natural phenomena [46,47]. The electromagnetic field of planet Earth is non-uniform. Electromagnetic landscapes are formed by the interaction of the geomagnetic field, atmospheric electromagnetic fields, and other local sources of electromagnetic radiation (biogenic and/or anthropogenic) [46,47,53,54].

The Earth is the first important source of the natural component in the formation of the electromagnetic field. According to the officially accepted scientific geophysical model, it has a stationary magnetic field. The geomagnetic field is formed as a result of the flow of electric currents in the highly conductive outer layer of the Earth's liquid core. The Earth's natural geomagnetic field is approximately 25 to 70 μT (averaging about 50 μT) and fluctuates between approximately 35 and 70 μT, depending on geographic location [66–69]. The magnitude of the geomagnetic field induction varies from the equator to the poles from approximately 25 to 65 μT, and its direction varies spatially in a rather complex manner. In the Northern Hemisphere, the field vector is oriented toward the Earth; in the Southern Hemisphere, it is oriented away from the Earth [66–69]. Its main quantitative characteristic is intensity. It has existed on planet Earth for approximately 3 billion years. According to paleontological studies, 188 reversals have occurred over 80 million years, with an average polarity interval of about 400 thousand years. Currently, a decrease in the geomagnetic field is observed. Its "zeroing" is expected in approximately 2000 years. At the magnetosphere boundary, the geomagnetic field transitions into the interplanetary magnetic field associated with the Sun and rotating with it [66–70]. The variable component of natural magnetic fields is represented by low-frequency fluctuations, mainly caused by various processes in the Earth's magnetosphere-ionosphere and the solar corpuscular flow. The range of natural magnetic fluctuations rarely exceeds 100 nT; the overwhelming majority of natural variable magnetic fields are recorded at frequencies up to 10 Hz [71,72]. The Earth's electromagnetic field has a shape that can be approximated by the expression "magnetic dipole". However, local variations in Earth's electromagnetic field can cause the strength and shape to fluctuate over time on scales of milliseconds and hours [70,73].

It should be noted that the main geomagnetic field is locally supplemented by magnetic fields generated by the magnetization of rocks (anomaly fields) [74]. For example, during the formation of rock sections with different densities, gravitational steps and anomalies may form between them, with differences in gravitational acceleration reaching 1%. Geopathogenic zones may arise above deep faults in the Earth's crust (10–15 km wide, hundreds of kilometers long), over which streams of ionizing radiation and gas rise into the atmosphere, generating electromagnetic effects and infrasound. Deformations of the Earth generate low-frequency (infra) acoustic waves in the Earth's crust, a range of the acoustic spectrum that is inaudible to the human ear, but which has significant biological activity and affects the emotional and mental state of a person (weather sensitivity and infrasound) [70,74,75]. Other physical fields are also important. Thus, the Earth's gravitational field is the result of fundamental scientific concepts that postulate that gravity is a physical field that cannot be shielded from [76,77], and that it also determines the conditions for the development of biota on Earth [70]. The gravitational component of the force of gravity at Earth's surface is not constant and depends on the distribution of mass in the Earth's crust [78]. The force of gravity depends on cosmic influences that define the

concept of "gravitational instability" [79]. The most studied dependencies are those on the Sun and the Moon (sea tides, deformation of the Earth's solid body, etc.) [70]. For example, the Moon changes the gravitational field of the space over which it is located to the greatest extent during the new Moon, and to the least extent during the full Moon [80]. All this creates yet another additional cosmic rhythm, which sets yet another rhythm for living organisms. All changes in the natural electromagnetic field, despite their small values, have significant effects at the biological level [5,6,70].

The atmosphere is the second fundamentally important source of the formation of the natural electromagnetic field. The current systems of the Earth's magnetosphere and ionosphere are the atmosphere's electromagnetic fields. They make a fundamental contribution to the formation of the Earth's electromagnetic field and its local landscapes. Electromagnetic fields of the atmosphere arise under the influence of the flow of cosmic electromagnetic energy (mainly the Sun) [81,82]. Due to this, a complex electrical environment exists in the atmosphere, formed by a complex combination of the interaction of such electromagnetic phenomena as the global electric circuit [83,84], local lightning strikes [85,86], electromagnetic wave processes, their resonances—standing waves/solitons (Schumann resonances, spherics) [46,87], wave processes of the visible and other ranges, ionization processes and ions [55]. All this together leads to the generation of fluctuating atmospheric electric fields, which contribute to the creation of a unique electromagnetic environment for human habitation. Due to this, humans on planet Earth constantly live in the conditions of an electromagnetic landscape in the frequency range from 0 Hz (static fields) to 300 GHz—the classic upper range of electromagnetic field frequencies [46,47,53]. The combined interaction of the atmospheric and terrestrial components of the Earth's electromagnetic field formation has led to the existence of a characteristic range of the Earth's electromagnetic radiation spectrum, which consists of the following ranges in order of increasing frequency: radio waves, infrared radiation, light radiation, X-ray radiation, gamma radiation [55]. Different sections of the Earth's electromagnetic spectrum differ in how they emit and receive waves within their own sections. For this reason, there are no sharp boundaries between different sections of the electromagnetic spectrum [55]. The mechanisms of interaction between the Earth's electromagnetic field and human electromagnetic fields are described in more detail in the section "Human Being as a Component of the Earth's Electromagnetic Landscape".

3.1.2. Aspects of the Biological Role of the Earth's Electromagnetic Field

The Earth's electromagnetic field plays a fundamental biological role as the electromagnetic component of biological life [46,47,64,65]. This is an important scientific field, and research is ongoing. Currently, at the turn of the 21st century, advances in fundamental science are creating conditions for rethinking and further progress in understanding the essence of these phenomena in the physiology of biological organisms and of humans.

There is scientific evidence that short-term exposure to confined spaces, isolated as much as possible from Earth's magnetic field, has a beneficial effect on the human body. Increasing this period of isolation from the external magnetic field beyond twenty minutes becomes detrimental. After 20 min, processes begin in the human body that negatively affect a person's psychological and physical state. The longer the isolation, the more intense the changes [70,88]. Modern science has established that the interaction of electromagnetic waves with the human body is predetermined by their wavelength [89,90]. Radio waves have wavelengths much longer than the sizes of atoms. Since the wavelengths of radio waves exceed 0.1 mm (the frequency range is from 300 GHz to 3 kHz) [5,6,55], their propagation can be considered without taking into account the atomic structure of the medium. Therefore, the quantum properties of radio waves are manifested only for the

shortest waves adjacent to the infrared region of the spectrum and during the propagation of so-called ultrashort pulses with a duration of about 10^{-12} s–10^{-15} s, comparable to the oscillation time of electrons within atoms and molecules [5,6,55]. Infrared, including ultraviolet, radiation constitutes the optical region of the electromagnetic wave spectrum, in the range from 2×10^{-6} m = 2 μm to 10^{-8} m = 10 nm (in frequency from 1.5×10^{14} Hz to 3×10^{16} Hz) [5,6,55]. In the optical part of the spectrum, phenomena caused by the atomic structure of matter become significant. For this reason, along with wave properties, optical radiation exhibits quantum properties. Therefore, electromagnetic wave processes in living organisms and humans are located in this range [5,6,55]. X-rays and gamma radiation have short wavelengths. X-ray radiation consists of electromagnetic waves with wavelengths from 50 nm to 10^{-3} nm, corresponding to quantum energies from 20 eV to 1 MeV [5,6,55]. Gamma radiation consists of electromagnetic waves with wavelengths less than 10^{-2} nm, corresponding to quantum energies greater than 0.1 MeV. Therefore, in the field of X-ray and gamma radiation, the quantum properties of their influence on living organisms, including humans, come to the fore [5,6,55].

A theoretical study found that, for the interaction of electromagnetic fields between the human body and the external environment, radiation in the optical spectrum is of most significant scientific interest. A systematic analysis of existing scientific data led to the conclusion that optical radiation is the basis of biological life. This is based on several concepts.

First, humans are a link in the electromagnetic processes of the electromagnetic energy cycle on planet Earth, a chain of stages in which photon energy is transformed into other states and carriers. All biological energy transformations are supported by electromagnetic processes in the plant, animal, and bacterial kingdoms, according to existing natural food chains [91]. The energy cycle begins with the influx of solar photons to Earth. The power of solar radiation reaching Earth is 8.4×10^{16} W [91,92]. Due to the presence of an atmospheric "transparency window," the maximum incoming energy is in the visible and infrared spectra (approximately 45%) [91,92]. On Earth, photons are included in the second energy link of natural biometabolism—photosynthesis. This is a universal mechanism for ensuring biological life on Earth: the conversion of photon energy by plants into a carrier in the form of organic matter. Green plants absorb 0.02% of the solar energy that reaches Earth (4×10^{13} W). This provides all the Earth's energy [91,93]. The change in free energy in photosynthesis reactions during the conversion of 1 O2 molecule is approximately 500 kJ·mol^{-1}, while 8 quanta of light with a total energy of approximately 1470 kJ·mol^{-1} are consumed. The efficiency of solar energy utilization in photosynthesis is 34% [91,94,95]. This free energy comes from photochemical processes involving chlorophyll. It has been established that, upon absorption of photons in the visible range of the solar spectrum, electrons reach the highest biopotential in plant photosystems [91,94,95].

The energy metabolism of the animal kingdom constitutes the third link in the natural energy chain [91]. Carbohydrates, proteins, and fats are essentially carriers/accumulators of photon energy and serve as the primary nutrients for heterotrophs. In cellular respiration/biological oxidation, a key role is played by the flows of electrons and protons moving along the enzymatic conveyor—the respiratory chain. Cellular respiration provides the energy supply for all life processes of animals and humans [96,97]. It is fundamentally important that, from a comparison of the scale of reduction potentials of the components of the photosynthesis and respiratory chain systems, it follows that solar energy converted by π-electrons during photosynthesis is spent primarily on cellular respiration (ATP synthesis). At the beginning of the respiratory chain, the free energy reserve of π-electrons is 220 kJ·mol^{-1}. This means that before this, the energy of the π-electrons that had accumulated solar energy had decreased by only 21 kJ·mol^{-1}. This means that >90% of the solar energy accumulated in green plants is carried by excited π-electrons to the respiratory

chain of the mitochondria of animals and humans [91,98,99]. Thus, during metabolism, the energy of electrons from the highest energy level is discretely passed to the lowest energy level in the biosphere—the water level—and all metabolic transformations in living organisms and in the human body are electromagnetic processes that transform electromagnetic energy from near space, from the Sun.

Secondly, the nature and cyclicity of the influx of electromagnetic energy from near space/the Sun contribute to the formation of temporal energy rhythms and cycles in the electromagnetic landscape on planet Earth and in the human body [100–106]. The formation of the Earth's magnetospheric indicators depends on "space weather" [107–109]. The phenomenon of hydrogen plasma convection at a distance of 0.3 radii from the Sun creates an electromagnetic field that plays a fundamental role in all processes of solar activity. Changes in the solar electromagnetic field determine the cyclicity of solar radiation, the so-called self-oscillations. According to observations, the period of the Sun's self-oscillations is 22 years [110–112]. The Sun's global electromagnetic field, like Earth's, has a "magnetic rod" along its rotation axis. The average speed of solar radiation is 400 km/s. The phenomenon of movement and expansion of the corona's substance at a distance of several tens of solar radii from the surface is called the solar wind. The solar wind blows around all the planets and fills the entire interplanetary medium. Chemically, it is a hydrogen-helium mixture in an ionized plasma state. Physically, it is a moving, continuous, rarefied medium with a particle density of 9 particles per 1 cm^3 (in the Earth's atmosphere—10^{19} per 1 cm^3), in which gas-dynamic phenomena can occur and sound can propagate. The solar wind creates its own electromagnetic field and reaches the Earth after 4.5 Earth days. During this time, the Sun rotates by 60°, and the lines of force of the solar wind's electromagnetic field bend, maintaining their connection to the Sun's electromagnetic field. This determines the sectoral structure of the interplanetary electromagnetic field: some of its lines of force extend toward the Sun's northern magnetic field, while others extend toward the southern magnetic field. The magnitude of the electromagnetic field of the solar wind is 0.7–70 nT (on average, 7 nT). The plasma density in the solar wind is 0.1–140 particles per 1 cm3, and the velocity is 150–1000 km/s. During a powerful chromospheric flare, the parameters increase, reaching maximum values and velocities close to the speed of light (300,000 km/s). A strong chromospheric flare on the Sun directs a plasma cloud toward Earth, which alters the spectrum of electromagnetic (wave) solar radiation, causes magnetospheric disturbances/storms, and induces fluctuations in magnetospheric parameters of the habitat [113–115]. All this determines cosmic ecological parameters on Earth and is of fundamental biological and medical significance, causing phenomena of heliochronobiological and meteorological dependence [116–120]. During a magnetic storm, numerous rapid changes in magnetic field intensity are objectively recorded, accompanied by a "storm" in infrasound—a biologically active range of the acoustic spectrum inaudible to humans. Infrasound spreads across an entire hemisphere of the Earth, exerting an effect for several hours. The usual composition of the magnetic spectrum also changes due to a hundredfold increase in low and ultra-low frequencies absent from the typical spectrum [5,6,91,121,122]. A vast body of experimental evidence shows that the effects of cosmic influences are evident at all levels of biological organization—from single-celled organisms to the neurophysiological processes of the human brain. Cosmic processes even influence the results of purely chemical or physical laboratory experiments [91,123–125]. Biorhythmology is important for therapeutic practice, since it has been shown that the effectiveness of treatment depends on the correct choice of the phase of its onset [126–129]. The chronobiological influence on the daily, monthly, and annual cycles of biological function has been established for Schumann resonances, an important electromagnetic phenomenon and a component of the local electromagnetic landscape [46,47,130–132].

Thirdly, this is a modern deepening of ideas about the role of biophotons in the human body as the primary carrier of energy and information [133–135]. The development of this scientific knowledge has passed approximately a century from the moment of the appearance of the hypothesis of their existence [136–138], proof of the fact of generation of biophotons by living cells [139–142] and a comprehensive study of the phenomenon of ultra-weak emission of biophotons [134,143–164] to modern research of the issue [133,165–172] and the creation of working concepts of the mechanisms of electromagnetic cellular communication—the concept of biophoton signaling [173–175]. This layer of the latest knowledge demonstrates the key role of electromagnetic processes in the visible range of the spectrum in the processes of life realization and maintenance in living biological organisms and in humans.

Thus, by the end of the first quarter of the 21st century, there is a large body of scientific knowledge [176–178] that confirms the important biological role of the Earth's electromagnetic field in the emergence and course of bioelectromagnetic metabolic processes in biological organisms and humans, and also testifies to the existence of a conjugation of interactions between the electromagnetic fields of the human body and the external environment.

3.1.3. Biogenic Biospheric Electromagnetic Fields as a Component of the Electromagnetic Landscape of the Earth's Electromagnetic Field

Biogenic biospheric electromagnetic fields are electromagnetic fields generated by living biological organisms (biocenoses) of the Earth's biosphere and are an integral component of the Earth's natural electromagnetic environment. All living organisms—plants, fungi, unicellular and multicellular animals, and humans—along with geocosmic sources, generate electromagnetic fields and exhibit their own electromagnetic frequency characteristics [4,70,179].

Non-contact measurements of electrical activity have established the presence of and change in electromagnetic fields in higher plants in response to light exposure after dark adaptation, during mechanical damage, and so on [179–186]. This confirmed that plant electromagnetic fields carry physiological information about the plant's response to external influences. The range of electromagnetic field rhythms in plants is within hundredths and thousandths of a Hz [187–189]. This has long cast doubt on the existence of biopotentials in plants. Now, the fact that plants generate electromagnetic fields proves that the changing electromagnetic fields generated by solar irradiation of plant masses contribute to the electromagnetic field of the ground layer of the atmosphere. It has been established that vegetation responds to external electromagnetic fields and acts as a good electrostatic shield in the 0–10 Hz range [52,70,190]. A significant body of research has been accumulated on endogenous EMF/electromagnetic fields in the animal kingdom [70]. Insects' electromagnetic fields have specific informational value regarding their kinematics and communication processes [191–194]. This is of fundamental importance in the lives of birds, reptiles, and other animals [194–196].

Electromagnetic fields emitted by animals are recorded in the optical and microwave ranges, covering the infrared, orange-red, blue, and ultraviolet regions [70,197]. The phenomenon of ultraweak biophoton emission is characteristic of all animals and plants. The intensity of photon emission in living organisms fluctuates within the range of 10^{-19}–10^{-16} W/cm^2. The minimum detectable photon flux density in the cerebral cortex of an intact rat is $9.9 \cdot 10^{-17}$ W·cm^{-2}·s^{-1} with a 60% decrease in intensity after cardiac arrest; in the area of an isolated section of the hippocampus—10–19 W/mm^2 [133,198]; and so on. It has been established that animals generate radiation in the infrared and ultra-high frequency ranges, as well as endogenous coherent electromagnetic fields in the 250–800 nm range [70,199], which predetermine the processes of morphogenesis and regeneration of their bodies. For example, in the blastopore of the African frog embryo, the presence of an inwardly directed positive transepithelial current through the ectoderm of 100 mA/cm^2,

voltage gradients between the rostral and caudal parts, and the proximal and distal regions of the embryo were recorded [200]. It has been established that it is the electromagnetic fields of cells and the total electrical charges/indicators of their membranes that predetermine the scenarios of cellular morphological development [201]. This once again confirms that the phenomenon of biological life exists and occurs exclusively due to electromagnetic metabolic processes at the microlevel of the organization of living organisms and the human body [202].

The existence of animal biomagnetism fits within the generally accepted scientific concept of an energy cycle in nature [203]. The main energetic transformations of energy consist of the fact that the electrons of water are activated during photosynthesis [204], replenishing the electron pool of chlorophyll P680, as it loses its π-electrons under the influence of the Sun, and cellular respiration again generates water [205], the electrons of which are not capable of imparting chemical activity to it in the organisms of animals and humans. This is a constant cycle, which can be called the "energy electron wheel of life/biosphere" [5,6,70]. Thus, all organisms, including humans, assimilate the electromagnetic component of solar energy from plant and animal foods and, on this basis, continuously generate electromagnetic fields. A fundamental feature of the natural energy exchange chain in living systems, unlike nonliving ones, is their ability not only to absorb energy but also to produce new electromagnetic energy specific to the body's cells [4–6,70,206]. Thus, biogenic biospheric electromagnetic fields are a productive part of the phenomenon of biological life on planet Earth. They are generated when each living cell establishes a potential difference and emits electromagnetic radiation across its membranes, thereby forming electromagnetic fields of biogenic origin. On the one hand, the above testifies to the unity and universality of the fundamental aspects of natural energy exchange.

On the other hand, this indicates that each biological organism is a source of electromagnetic radiation and is/must interact with other electromagnetic fields in the Earth's electromagnetic landscape. Depending on their biospheric localization, biogenic electromagnetic fields can be classified as geobiospheric, hydrobiospheric, or aerobiospheric. Biogenic biospheric electromagnetic fields participate in the formation of the local electromagnetic landscape. The electrical landscape of any biome will be the product of the dynamic interaction between abiotic sources (e.g., potential gradient) and electromagnetic disturbances from living organisms. Ultimately, in almost all environments on Earth, abiotic and biotic components will serve as both sources and absorbers, as well as modifiers of electric fields and ions, which interact in an internally linked and reciprocal manner [7,50,70].

The energy of biogenic biospheric electromagnetic fields is too low to alter molecular structure or break molecular bonds [52]. For example, the maximum quantum energy of an electromagnetic field at a frequency of 300 GHz is 1.2 MeV, while 80 MeV is required to break the weakest hydrogen bond. In this regard, electromagnetic fields with a frequency below 300 GHz are usually called non-ionizing radiation [207]. However, even high-intensity non-ionizing radiation cannot cause ionization in a biological system [208]. Therefore, the influence of biogenic biospheric electromagnetic fields on the human body is associated with their biological effects [100,209,210]. Therefore, when studying electromagnetic interactions between the human body and the external environment, it is necessary to consider the potential influence of biogenic biospheric electromagnetic fields. For this reason, this aspect is an important scientific direction that requires further development. Of promising scientific interest in relation to the influence on the human body is further study of the role of the "electromagnetic landscape" of living nature—forests, fields, contact interaction with the animal world, and so on.

3.1.4. Anthropogenic Electromagnetic Fields as a Component of the Electromagnetic Landscape of the Earth's Electromagnetic Field

At the current stage of development of our human civilization, the spectral composition of the Earth's electromagnetic field landscape has been supplemented by artificial/anthropogenic electromagnetic fields. Technical means created by man emit artificial fields. The human-created electromagnetic environment consists of fields that are emitted intentionally or are the products of the use of other devices: power lines and transformer substations, electric transport, industrial equipment, radio telecommunication systems, local house distribution networks, and electrical equipment in the house (electrical wiring, power cables, built-in transformer substations, switchgear, etc.), and so on.

A systems analysis of the situation revealed that humanity now uses virtually the entire frequency range of electromagnetic radiation [31,209]: (1) up to 300 Hz (up to 1000 km)—static fields of various origins, power plants, power lines, video display terminals; (2) 0.3–3 kHz (1000–100 km)—radio transmitter modulators, medical devices, electric furnaces for induction heating, hardening, welding, melting, cleaning; (3) 3–30 kHz (100–10 km)—very low frequency communications, radio navigation systems, radio transmitter modulators, medical devices, electric furnaces for induction heating, hardening, welding, melting, cleaning, video display terminals; (4) 30–300 kHz (10–1 km)—radio broadcasting, radio navigation, maritime and aviation communications, low frequency communications, radar, video display terminals, electrophoresis, induction heating and melting of metal; (5) 0.3–3 MHz (1–0.1 km)—radio broadcasting, communications, radio navigation, marine radiotelephony, amateur radio communications, industrial radio frequency devices, amplitude modulated transmitters, welding machines, semiconductor material production, medical devices; (6) 3–30 MHz (100–10 m)—radio broadcasting, amateur radio communications, global communications, high-frequency therapy, magnetic resonance exciters, dielectric heating, wood drying and gluing, plasma heaters; (7) 30–300 MHz (10–1 m)—mobile communications, heating, frequency-modulated radio broadcasting, television broadcasting, ambulance, dielectric heating, magnetic resonance exciters, plastic welding, plasma heating; (8) 0.3–3 GHz (100–10 cm)—radio relay lines, mobile communications, radar, radio navigation, television broadcasting, microwave ovens, medical devices, plasma heating, particle accelerators; (9) 3–30 GHz (10–1 cm)—radar, satellite communications, mobile communications, meteorological locators, radio relay lines, security alarms, plasma heating, thermonuclear fusion plants; (10) 30–300 GHz (10–1 mm)—radar, satellite communications, radio relay lines, radio navigation.

According to a systems analysis, the source of the greatest anthropogenic generation of electromagnetic energy in the Earth's electromagnetic field is radio telecommunications systems [209–229]. This is due to the modern, evolving needs of the human community for communication and access to information, namely radio broadcasting, terrestrial television, and radio communications. Therefore, the radiating technical means necessary for their functioning are relatively evenly distributed across Earth's territory to create the required intensity of electromagnetic fields in areas of human presence. Moreover, the practical situation demonstrates that radiating technical means can be located within city boundaries, television centers, the most populated areas, and so on. This increases the risk of the emergence of high levels of electromagnetic fields from radiating technical means, which affect the population of nearby territories. Electromagnetic fields from radio telecommunications systems increase the intensity of natural electromagnetic fields several times [230]. In large population centers, where numerous mobile operator transmitters are located, electromagnetic field intensities are significantly higher, reaching 10–15 times the permissible limits [231].

Particular attention should be given to the development of land mobile communication systems as a component of anthropogenic electromagnetic field generation. On the one hand, there is a trend toward each person acquiring their own source of electromagnetic radiation—the mobile phone. At the same time, the situation regarding environmental electromagnetic literacy and awareness of the use of this equipment among the public remains unsatisfactory. Very often, these devices are used without adherence to standards or electromagnetic safety principles. On the other hand, the development of land mobile communication systems is accompanied by an increase in the number of base stations that uniformly cover territories. In developed countries, the number of base stations for land mobile communication systems is tens of thousands [232]. This significantly increases the local electromagnetic load on Earth's electromagnetic field. The large and constantly growing number of mobile phones and base station transmitters may potentially influence the electromagnetic situation in the biosphere, despite their low power [233,234]. This issue requires further in-depth study.

In principle, every generator acts as a source of an electromagnetic field and can cause harmful effects depending on the levels of radiated power. The total number of industrial, scientific, and medical installations worldwide that emit electromagnetic fields is estimated at several hundred million, and this number is constantly increasing. In 1992, their number was 120 million, and this figure has now increased significantly [235]. These devices are important components of modern technologies, including those used in industrial, medical, and scientific applications. However, in their vicinity and in the vicinity of power lines, transformers, and other electrical devices, an electromagnetic field with a constant frequency of 50 Hz is generated, which can have varying intensity depending on the voltage flowing through the network, the distance from the conductor, meteorological conditions, and other factors [233]. This undoubtedly introduces significant changes into the local electromagnetic landscape of the human environment. It is important to note that the widespread computerization of all spheres of human activity has led to prolonged exposure of people to electromagnetic fields from computer equipment. There is a trend toward a sharp increase in the number, types, and power of household appliances in the very limited space of a modern home. This is indirectly evidenced by the increased consumption of electrical energy in everyday life. For example, over the past decades, the current ratings of fuses and circuit breakers at the input of the power grid in apartments have increased from 5–6 to 35–40 amperes [234]. This represents a 50–70-fold increase in power consumption and, consequently, a 5–8-fold increase in electromagnetic field levels in apartments. It is also necessary to consider the presence of electromagnetic fields generated by various metal structures and building pipelines that are galvanically connected to the grounding or earthing of the power supply system [235]. Thus, anthropogenic changes to the local electromagnetic landscape of the Earth's electromagnetic field in areas directly populated by humans are quite significant and can lead to indicators that negatively impact the human body.

Thus, as a result of the constant increase in anthropogenic sources of electromagnetic energy of various types, with widely varying spectra of emitted fields, the Earth's electromagnetic landscape is tending toward a quasi-continuous state. Anthropogenic electromagnetic radiation creates a complex, ubiquitous mixture of artificial fields in the Earth's electromagnetic landscape, altering the natural background environment to a densely packed, continuous electromagnetic spectrum.

Further study of the effects of anthropogenic electromagnetic fields on biological organisms and humans is undoubtedly important, given their growing contribution to Earth's local electromagnetic landscapes.

3.2. Bioelectromagnetism of the Human Organism and Electromagnetic Fields of the External Environment

Based on the conducted systems analysis, it was concluded that humans, as biological organisms, are a component of the Earth's electromagnetic landscape and interact with external electromagnetic fields. This assertion is supported by magnetoelectrochemical aspects of human body function, evidence of synchronization of the body's bioelectrochemical processes with the electromagnetic environment of planet Earth, and mechanisms of interaction between the human body's electromagnetic fields and the external environment already discovered by science.

Humans are complex, nonequilibrium energy systems, which can be considered the highest link in the natural energy chain, adapted to absorbing many types of internal and external energies. During its life processes, the human body generates electromagnetic radiation across a wide range of frequencies, which is apparently specific to Homo sapiens. The human body has a total electromagnetic field with frequencies of 10^{-4}–10 Hz. It distinguishes between low-frequency fields, including quasi-static fields, and high-frequency fields in the radiofrequency, optical, acoustic, and infrared ranges of the electromagnetic spectrum. Depending on the source, the electromagnetic fields of the human body can be classified as follows: (1) electromagnetic fields of individual organs; (2) electromagnetic fields/electrostatic fields caused by the surface electric charge on the body; (3) electromagnetic fields caused by processes of the electrophysical properties of tissues (electrical conductivity, permittivity, etc.) [4,197].

The following field parameters have been established for the human body: electrostatic field strength is up to 80 V/m (15 ± 2.0 V/m); surface density of electric charges is 10^{-5}–10^{-8} C/cm^2; electrostatic field potential relative to the Earth at a distance of 10 cm from the body surface is from 2–3 to 300 mV; triboelectric charges on the body surface are up to 13 kW; the constant and alternating magnetic field of the human body has a frequency of 0.1–400 Hz; electromagnetic fields of individual organs have an amplitude of 1–5 mV and frequencies of 0.001–400 Hz; the magnetic field of the heart is 0.05–0.07 mT (10–6 T); the magnetic field of the brain is 0.1–0.07 nT (10–9 T); the magnetic field near the human head is of the order of 0.01–0.1 pT and is identified as the α-rhythm magnetic field; the electromagnetic fields of nerve action potentials are approximately 150 μV at a distance of 12 mm from the trunk; the magnetic field of muscles is approximately 0.1 mT; macroscopic loop ion currents with an amplitude of up to 12 μA have been detected in human legs, changing according to muscle tone; the intensity of photon emission on the body surface is <10–16 W/cm^2 with a maximum on the face, hands and feet, with the greatest intensity in the blue and red parts of the optical range, and a section of intensity in the ultraviolet part of the spectrum; in the area of biologically active points, there is a sharp increase in the potential of the electromagnetic field [70].

3.2.1. Magnetoelectrochemical Aspects of the Human Body Functioning as the Basis for Interaction with the Electromagnetic Environment of Planet Earth

From the standpoint of modern fundamental biophysical knowledge, the human body, when examined at the micro level of its structure, is a complex conglomerate of electromagnetic energy/electromagnetic field structures and electromagnetic processes [4]. This is so because, according to the Standard Model, each atom of the human body is formed by electromagnetic field structures—fermions and bosons—and has specific frequency-wave characteristics according to the Law of Frequency-Wave Duality [1–3], like all other atoms on planet Earth. The result is that molecules are conglomerates of the frequency-wave/electromagnetic parameters of the atoms that form them. This is also true for tissues, organs, and the entire human body [4,179,202,236]. Therefore, it is absolutely logical that the human body, formed at the micro level by electromagnetic field structures/processes,

can and should, in accordance with universal physical laws, interact with external electromagnetic processes in the surrounding environment.

The human body is characterized by a multi-level hierarchical structure: from the atomic level to the level of the entire organism [237]. At the present stage of science, it has been established that matter has subatomic/quantum levels of structure. The functioning of each level of the hierarchical structure of the human body, from the biological cell to the organ systems, is conditioned and ensured by electromagnetic processes [202,206,238,239] (Figure 3 on the right).

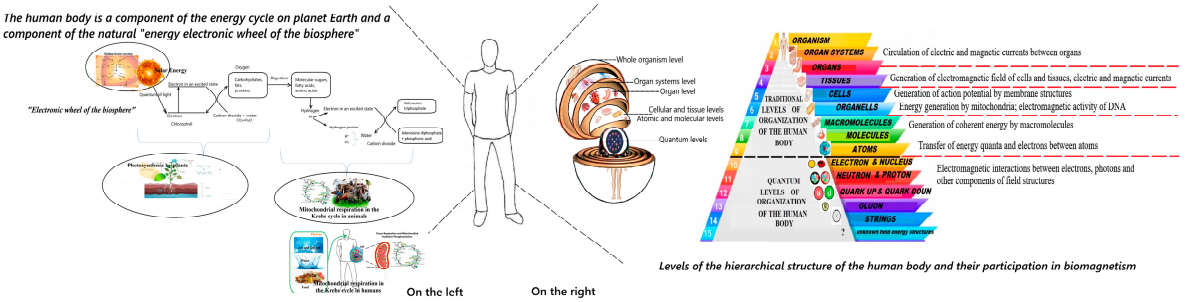

Figure 3. Fundamental aspects of biomagnetism of the human body. Excerpts from [240] are used. Note: On the left is a diagram of human participation in the energy cycle of planet Earth; On the right, there are two diagrams of the hierarchical levels of human structure and their participation in biomagnetism.

Electromagnetic metabolic processes in the human body are part of the energy cycle on planet Earth and the so-called natural "energy electronic wheel of the biosphere" (Figure 2, left). The intensity of electromagnetic metabolic processes in the human body is such that approximately 300 mL of endogenous oxidation water is formed per day at rest during biological oxidation. The volume of its formation is determined by the intensity of metabolism, the type and mass of oxidized substrates of cellular respiration: the oxidation of 100 g of fat produces approximately 100 mL of water, 100 g of protein and 100 g of carbohydrates—40 and 50 mL, respectively. Moreover, a fundamental feature of the natural energy exchange chain in living organisms and the human body is the ability of their cells to produce specific electromagnetic energy with individual physical parameters of their electromagnetic fields [5,6,202]. Bioelectromagnetism in living organisms and the human body is a well-established paradigm [29]. A large body of fundamental scientific discoveries has been devoted to investigating the mechanisms of electromagnetic field generation and the parameters of electromagnetic fields in human organs. The electrical and magnetic activity of tissues and organs has been sufficiently studied [29].

The mechanisms of the generation of electromagnetic fields in the human body continue to be studied. Previously, scientists focused their attention on the chemical processes in membranes associated with the generation of action potentials [240]. Thanks to the development of quantum physics and progress in fundamental science, the fundamental role of photons as carriers of magnetic fields in the transfer of energy and information has been understood. The corresponding aspects, theorized at various times by biophysicists, formed the basis for the concept of biophoton signaling and are described in detail in reviews [173,174,241] and in monograph chapters [175,202]. These theoretical studies have yielded a biological description of the mechanisms by which electron/photon/polariton effects arise during coherent collective oscillations of biomolecules in biological cell membranes, and how they are transmitted as solitons/polaritons through the biopolymers of biological cells and the liquid-crystalline water molecules *in vivo*. This concept is essentially a biological description of the biophysical processes of the generation and propagation of electromagnetic fields in cells and tissues of the human body *in vivo*. Overall, it provides

a scientific explanation for how non-chemical/electromagnetic communication between molecules within a cell and between cells *in vivo* is realized. This is now very important for studying the interaction of the human body's endogenous electromagnetic fields with external electromagnetic fields.

The presence of biophotonic electromagnetic mechanisms underlying DNA functioning is another important aspect of human biomagnetism, deepening our understanding of the possible mechanisms and points of application of the interaction between biological cells and external electromagnetic fields. Thus, DNA is an excited duplex/exciplex system that absorbs electromagnetic energy in the form of photons and accumulates it between its two strands due to the peculiarities of its spatial conformation and the phenomenon of Bose–Einstein condensation [242]. Biophotonic mechanisms stabilize the DNA molecule and enable electromagnetic signaling from DNA, as evidenced by the emission of biophotons [140,167,173–175,242,243]. A modern working model of biomagnetism in biological cells describes DNA as a generator of the informational electromagnetic component of the cell's internal electromagnetic field in the millimeter wavelength range, with a frequency of 1010–1011 Hz [173–175,202,244]. The biophoton signal from DNA ensures the virtually instantaneous flow of information from genes to all cell compartments and to membrane biopolymers. Biopolymers of the cell membrane structures, due to their constant oscillations, generate coherent electromagnetic energy in the form of biophotons in the state of standing waves—solitons with a wavelength of >1 μm to 0 and an energy of <0.5 eV and up to 0. This forms a specific electromagnetic current/flow of biophotons, which further becomes a carrier of energy and genetic information from DNA. Continuous in vivo movement of this electromagnetic current between the molecules of biopolymers and the liquid-crystal structures of water creates unique conditions for the maintenance of constant electromagnetic communication between cellular molecules. This makes them alive in vivo, coordinates their metabolic behavior, and unites them into a single functional entity called "human body cells" [173–175,202]. This confirms the relevance of further developing human body biophotonics as a scientific field that can form the basis for understanding the fundamental mechanisms of interaction between the human body's electromagnetic fields and those of the external environment.

It has been established, and is already common knowledge, that the membrane structures of biological cells generate electromagnetic fields. The unification of the electromagnetic fields of tissue cells, according to the universal principles of Field Theory, creates the electromagnetic field of individual organs of the human body, and so on [4,202]. At the macro level, the electromagnetic fields of the human body are the sum of two components: the body's own electromagnetic field, created by the electrical activity of individual excited organs (the brain [245–248], the heart [249–252], and so on), and the magnetic fields induced by the movement of conductive fluids (electrolytes), such as blood and lymph [253]. The currents induced by the external magnetic field generate a secondary magnetic field in the body, acting inductively on the nervous system and directly on functional systems [70,253]. Scientific work on the electrophysiological aspects of human body function continues.

When examining the mechanisms of formation of electromagnetic fields depending on the range, it was established that the causes of the occurrence of low-frequency electromagnetic fields in the human body are, in all likelihood, the following mechanisms [4]: (1) Transmembrane potential difference formed due to diffusion and active transport of molecules and ions through membranes, which leads to the accumulation and separation of ions of different signs on the membranes and creates a quasi-static field in this area. (2) Inductive interactions: electret effects caused by the orientation of polar molecules and the occurrence of a field due to the uncompensated charges due to the spatial distribution of electromotive forces associated with cellular and tissue metabolism, which ultimately leads

to the emergence of a complex bioelectret structure of the entire organism. (3) Redistribution of charged elements within the body with their polarization in the electric field, and the formation of double electric layers on cellular and other inhomogeneities, which leads to the formation of significant volumetric charges, the spatial movement of which causes the formation of an electromagnetic field within the body with different parameters depending on the speed of movement of charged elements, biorhythms, molecular organization and other metabolic processes.

The generation of the high-frequency component of the human body is highly diverse. The causes of ultraviolet radiation include the recombination of free radicals; lipid peroxidation; the destruction of biomolecules; intramolecular rearrangement of the electronic structure of high-energy biomolecules; and cell division [4].

Infrared radiation is considered associated with all metabolic processes [70,197]. Radio waves, including acoustic ones, occur during electrogenesis phenomena during the passage of impulses along neurons; during the movement of cells and villi, contraction of muscle fibers, intestinal peristalsis, heart function, etc.; during changes in the electronic structure of macromolecules; and during biochemical, biophysical, and immune reactions [70,197].

Piezobiosynthesis is another important source of the endogenous electromagnetic field. Mechanical deformation of liquid-crystal biological structures leads to polarization and the emergence of a piezoelectric effect [254–256]. Collagen fibers of tendons, bones, and fibroblasts exhibit piezoelectric properties, since collagen protein molecules form long, thin, flexible threads and organize parallel structures that possess liquid-crystal properties because chains of tropocollagen molecules combine with water molecules into cluster systems [257–261]. Since connective tissue is distributed in virtually all organs, forming flexible structural "frameworks" for them [262], many tissue structures exhibit piezoelectric properties. It has been established that the most pronounced piezoelectric effect, that is, the ability to convert mechanical compression-extension energy into electrical energy, is possessed by muscular-tendon, as well as perineural, perilymphatic, and perivascular connective tissues [197,254]. Thus, muscle movements generate a piezoelectric effect, converting the chemical energy of adenosine triphosphate into mechanical energy, which is then converted into electrical energy. The resulting electromagnetic energy/biophotons propagate along longitudinally oriented collagen fibers along muscle synkinesis and along the Primo-Vascular System (PVS) [173,175].

Thus, the generation of endogenous coherent electromagnetic fields in the 250–800 nm frequency range by living biological cells/tissues, as well as radiation in the infrared and ultra-high-frequency ranges, is the main electromagnetic manifestation of biological life [4,202,206,238]. From the standpoint of modern biophysical knowledge, it becomes obvious that the human body is a complex, multi-level, hierarchical electromagnetic system that is integrated into the general system of biological life and into the energy exchange on planet Earth. Bioelectromagnetic waves/bioelectromagnetic energy of the human body is an objectively existing, scientifically proven phenomenon that contributes to the electromagnetic fields of the biosphere, formed by the frequency-wave processes of living biological organisms on planet Earth. It makes scientific sense to consider the magnetoelectrochemical aspects of the human body's functioning as the basis for understanding the mechanisms of interaction between the endogenous electromagnetic fields of the human body and the electromagnetic environment of planet Earth.

3.2.2. The Concept of Synchronization of Bioelectrochemical Processes of the Human Body with the Electromagnetic Environment of Planet Earth

The interaction between the electromagnetic fields of the human body and the external environment is beyond doubt, since biological tissues of living organisms consist of substances that carry electrical charges, and primary electromagnetic processes govern all

vital functions of organ cells. The existence of cause-and-effect relationships confirming the interaction of the bioelectrochemical processes of the human body with the electromagnetic environment of planet Earth has been scientifically proven [263–265]. For example, it has been established that living organisms and humans cannot function normally without exposure to natural electromagnetic fields [263,266–269]. It has also been scientifically proven that excessive environmental saturation with anthropogenic electromagnetic fields ("electromagnetic pollution") can lead to stress in living organisms, deterioration in health, and the death of biological organisms [89,270–274], and so on. These relationships exist, but they have not been thoroughly studied and understood by science. However, even these facts alone are sufficient to justify the existence of mechanisms coupling internal electromagnetic fields and processes in living organisms with those of the external environment.

According to a systematic analysis of the scientific literature, synchronization of the bioelectrochemical processes of the human body with the electromagnetic environment of planet Earth is the most promising working concept to explain the biological meaning of these phenomena [176,263,275,276].

On the one hand, the idea of possible synchronization with the electromagnetic field is logical, based on scientifically proven facts about the electromagnetic aspects of the structure and functioning of the human body. On the other hand, the natural human habitat is electromagnetic. The Earth's external electromagnetic fields constantly surround the human body and interact with it. The electromagnetic environment of planet Earth can rightfully be called another "seventh ocean of the planet," in which humans are immersed. [This is conditional and based on calculations that there are five water oceans and one air ocean].

Modern scientific data suggest that living organisms and humans synchronize with external electromagnetic fields. The phenomenon of synchronization of processes is recognized as a universal phenomenon in biology. Synchronization is observed in many living biological systems [277]. This is a process of interrelation and mutual influence between objects/systems that oscillate in time with a fixed phase relationship between them. The classical theory of synchronization is based on the idea of self-sustaining periodic oscillators. According to this, if an autonomous oscillator is exposed to an external periodic force of the appropriate amplitude and frequency, the oscillator's oscillations will synchronize with the external signal. This allows us to distinguish between phase and frequency synchronization [278,279], and this is theoretically applicable to the interaction between "internal electromagnetic fields of humans" and "external electromagnetic fields of planet Earth." If we analyze the interaction between the electromagnetic field structures/processes of the human body and the Earth's electromagnetic field, we can postulate that, during evolution, the human body may have been phase-synchronized with the background electric fields of the atmosphere [46,47]. For example, today, Schumann resonances are considered one of the natural factors through which the mechanism of the electromagnetic influence of planet Earth on the course of magnetoelectrochemical metabolic processes in the human body is realized [46,47].

The logic of this conclusion is based on the following knowledge. Firstly, electromagnetic fields have existed on planet Earth for billions of years, since the onset of volcanic and thunderstorm activity. They maintained a natural background field of extremely low frequencies throughout the planet, with a specific maximum frequency and a fundamental mode of approximately 8 Hz (as has now been proven and understood by science) [280]. Therefore, it is generally accepted that the Earth's electromagnetic fields are a natural electromagnetic background for the existence of biological life [277]. Moreover, the influence of electromagnetic fields also extends to the biosphere of the aquatic environment of planet Earth. For example, it has been established that extremely low frequency waves with a

planetary wavelength can penetrate hundreds of meters into the photic zone of the oceans (the sunlit upper water column). A total of 100 m is the estimated penetration depth of electromagnetic waves with a frequency of 8 Hz in seawater [281]. The above demonstrates the relative omnipresence of Earth's electromagnetic fields as a biologically significant factor in the maintenance and evolution of life on Earth. It also supports the existence of biological synchronization between the human body's bioelectrochemical processes and the electromagnetic environment of planet Earth, as a biologically intended purpose of Nature. This, in turn, suggests that mechanisms for electromagnetic interaction with the environment's electromagnetic fields must exist and be realized within the human body.

3.3. Mechanisms of Interaction Between Electromagnetic Fields of the Human Body and the External Environment

3.3.1. General Concepts About Electromagnetic Effects on the Human Body

The type and mechanism of interaction between the electromagnetic fields of the human body and the external environment depend on the parameters of the acting field (intensity, frequency, modulation type, structure, etc.), the characteristics of the biological systems exposed (size, shape, and position of the biological object relative to the propagating electromagnetic field, etc.), and the duration of exposure [282–287].

In theoretical research on the interaction between external electromagnetic fields and the human body, two fundamentally important aspects have been identified. Firstly, all external electromagnetic fields overlap in space in accordance with physical laws, and their effects on living biological organisms are realized through the combined electromagnetic field that forms at a specific location [287–290].

In science, electromagnetic radiation from a single electromagnetic field source is considered isolated. Radiation from two or more electromagnetic field sources with the same maximum permissible level of the same regulated parameter is considered combined. Radiation from two or more electromagnetic field sources with different maximum permissible levels for one or more standardized parameters is called mixed. There is a combined nature of electromagnetic exposure, in which an additional influence of another unfavorable polluting factor (material or energetic) occurs alongside electromagnetic exposure [90,291–293]. A person can be in the electromagnetic field's zone of influence constantly or temporarily. Temporary exposure refers to intermittent exposure [89,294]. A typical example of intermittent exposure is irradiation from scanning antennas of radar stations [295]. The entire human body can be exposed—this is general irradiation. Irradiation can be local, when individual parts of the body are exposed to external electromagnetic fields [89,296]. For example, irradiation of the head area by electromagnetic radiation when using a radiotelephone/mobile phone [297], and so on. In this regard, the impact of external electromagnetic fields on humans can be classified as intermittent or constant, local or general, combined from several sources, combined with other unfavorable environmental factors, and so on.

Secondly, the human body accumulates energy from exposure to surrounding electromagnetic fields over time [298,299]. Therefore, in several clinical cases, delayed adverse effects can be expected, which will be difficult to anamnestically associate with a specific time period during a specific zone of adverse electromagnetic influence. In this regard, a quantitative assessment of the danger posed by electromagnetic influence should be conducted, taking into account the field intensity, power flux density, duration of irradiation, and the functional state of the human body exposed to it. It is necessary to take into account the environment surrounding the biological object: the presence of grounding and reradiating structures, the parameters of underlying surfaces, and so on. Moreover, the limit values should be determined based on the frequency range and differ for magnetic and electric fields. People with chronic internal organ diseases/non-communicable diseases (NCDs)

may be considered more susceptible and prone to accumulate electromagnetic energy from exposure, due to increased levels of free radicals in their bodies resulting from pathogenic activation of lipid peroxidation [300,301]. Peroxidation is one of the universal pathogenetic mechanisms of the occurrence and progression of NCDs [302–304]. Moreover, it creates conditions for increased affinity of biological cells to absorb electromagnetic energy from external influences, due to their increased formation of free radicals [305,306].

In the human body, the electrical properties of biological cells vary across tissue types and are determined by the complex permittivity, electrical conductivity, and dielectric loss tangent [307]. Significant differences in the electrical properties of different tissues and organs result in a complex picture of the possible distribution of electromagnetic energy from external influences entering the body [308]. Possible calculations of such a distribution and the possible release of thermal energy remain uncompleted in science. An important practical aspect is that, when exposed to external electromagnetic fields, the effective surface area of the human body depends on the field frequency [309,310]. Therefore, this parameter can vary significantly depending on the area of the body's projection onto planes perpendicular to the incident wave. The purpose of analyzing the level of exposure to an electromagnetic field is to establish the average values of absorbed energy for individual areas (organs) and/or a picture of the distribution of absorbed energy throughout the hu

An analysis of literature data on the presented problem shows that, due to the increased anthropogenic contribution to Earth's electromagnetic landscape, combined electromagnetic influences are the most common form of exposure to external electromagnetic fields for humans.

An important criterion for assessing the potential impact of external electromagnetic fields on humans is the frequency of the field. It has been established that, with increasing frequency, the maximum permissible exposure level decreases [311–313]. For example, an influencing factor is contact currents between a person and a charged object. At field frequencies below 100 kHz, human contact with such an object will stimulate electrically excitable tissues and cause pain [314]. At high current densities, tissue damage, such as burns [315], is possible. For frequencies between 100 kHz and 100 MHz, the risk of burns from contact current on the human body increases [315]. Therefore, higher frequencies should be subject to stricter standards.

In view of the above, quantitative assessments of the parameters and thresholds of external electromagnetic fields are necessary to objectify their possible impact on the human body practically. Therefore, the dosimetric approach remains the primary method of objectification [311,316]. It is based on the principles of classical electrodynamics, according to which the effects of an external electromagnetic field on the human body are determined by the amount of electromagnetic energy absorbed by the body over a given period of time [287,317]. The influence of external electromagnetic fields is considered a consequence of phenomena occurring in a dielectric substance and depends on its electrophysical parameters: specific electrical conductivity and permittivity [318]. The most commonly used parameters are Specific Absorption Rate (SAR), Power Density (S), Induced Electrical Field Strength & Current Density, and Electromagnetic Field Intensity [319–322].

Field intensity is the primary dosimetric value of an electromagnetic field with a frequency above 300 MHz. This term refers to the energy flux density in watts per square meter (W/m^2) (or mW/cm^2 and $\mu W/cm^2$) [320]. Radiofrequency fields cause severe adverse effects on human health at energy flux densities exceeding 1000 W/m^2 [272]. Such electromagnetic landscape parameters arise in areas around powerful radar stations [323,324].

The SAR parameter characterizes the specific absorbed power and reflects the amount of electromagnetic field energy absorbed by a unit of mass of a biological object in watts per kilogram (W/kg) or milliwatts per gram (mW/g). As a rule, SAR is averaged over the

total mass of the human body and over its individual parts (e.g., the mass of organs). It is possible to define a differential value as the ratio of the energy absorbed by an infinitesimal volume element to its mass [322,325].

The parameters induced electric field strength or current density are of practical importance due to their potential impact on the human body [287,322]. For example, radiofrequency fields at frequencies below 100 kHz can induce sufficiently high current densities that will stimulate excitable tissue (e.g., tissue of the nervous and/or muscular systems of the human body) or create other negative effects [326].

It goes without saying that, to ensure electromagnetic ecology, the categories of people exposed to radiation and the types of technical equipment they use must be taken into account. Principles for increasing safety/protection from anthropogenic external electromagnetic radiation should be applied based on the category to which a particular person belongs: the general population, industrial personnel, and so on.

3.3.2. Effects and Mechanisms of Electromagnetic Influence on the Human Body

Based on a theoretical study of the problem, three main types of mechanisms of interaction between external electromagnetic fields and the human body were identified: (1) mechanisms explained from the standpoint of classical electrodynamics; (2) quantum mechanisms; (3) biological mechanisms.

Mechanisms of interaction are explained from the standpoint of classical electrodynamics. The study of the interaction between the endogenous electromagnetic fields of the human body and external electromagnetic fields within the framework of classical and quantum electrodynamics is a traditional approach in modern science. Classical electrodynamics accounts for the influence of external electromagnetic fields on the macroscopic properties of matter [327,328]. According to the laws of physics, the passage of electromagnetic waves through various media in the human body is accompanied by reflection, refraction, and transmission/absorption of this energy by the molecules of biological cells of the human body, depending on the electrical parameters of the media, the field frequency, and the angle of incidence. After this, the energy absorbed by the cells is converted into other forms, which can cause changes in their functioning at the micro- and macrolevels of the human body. Since most of this absorbed energy is transformed into thermal energy, tissue heating has long been considered the main biological effect of exposure to an external electromagnetic field [53,89,319]. It was believed that in the living human body, the most vulnerable environments to physicochemical changes caused by tissue heating are tissues and organs with poor blood circulation, which cannot actively remove heat. For example, this includes the lens of the eye, the brain, the gallbladder, and the stomach [326,329,330].

Based on this approach, the most biologically active radiation is in the ultra-high-frequency range (3–30 GHz), the least active is ultra-high-frequency radiation (300–3000 MHz), and the third most powerful is high-frequency radiation (100 kHz–30 MHz). A general pattern is that the shorter the wavelength, the greater the effect's intensity [287,331,332]. Since no direct thermal effects occur when external millimeter-range electromagnetic fields affect the human body, their biological effects have previously been denied or described in studies as debatable [274,333].

Atom ionization is another important mechanism underlying biological effects resulting from external electromagnetic fields acting on the human body. When the energy of high-frequency photons in an electromagnetic field exceeds the binding energy of electrons in an atom, they are knocked out, forming free radicals [287]. This process leads to the formation of a large number of free radicals and ions. This results in oxidative stress and the disruption of the integrity of biomolecular membrane structures. The biological adverse effect is damage to cell membrane components, disrupting their function and destroying

biological macromolecules (DNA, proteins), leading to the development of pathology and potentially causing cell death. The involvement of oxidation mechanisms is described in detail in the review [52].

Quantum mechanisms. Quantum electrodynamics studies the mechanisms by which external electromagnetic fields influence the human body, drawing on quantum field theory and the microstructure of matter. The concepts of quantum physics and the modern development of Information Fields Theory [334] have significantly expanded and refined ideas about the possible mechanisms of electromagnetic influence on the human body. A systematic analysis of existing scientific data has shown that the key mechanisms of the appearance of the biological effects of electromagnetic influence on the human body at the subcellular levels of its structure are mechanisms associated with changes in the quantum-mechanical properties of ions, atoms, and the molecules they form, and hierarchical systems (for example, aqueous liquid-crystal structures, etc.). This is so because, according to modern physical knowledge, at the microlevel of their structure, all atoms of substances are formed by electromagnetic energy in its various states in the form of a combination of fermions and bosons [1–3]. Therefore, all atoms of substances are characterized by specific electromagnetic characteristics of their quantum-mechanical state [335]. Accordingly, all tissues, molecules, atoms, and subatomic structures, as well as all microlevel processes (nanolevel and deeper), exhibit the properties of frequency-wave dualism. They are the result of electromagnetic interaction [4,202]. For this reason, in the human body, each atom, ion, and molecule has its own characteristic frequency, and it can resonate with the environment's resonant frequency. This theoretical aspect is supported by the established existence of bioeffective frequencies in the range of 0.3–30 Hz [336], which cause resonance of bound ions. In this case, ions can be considered as isotropic oscillators carrying a charge. In the scientific literature, it is known as cyclotron resonance [337–340]. This mechanism is realized at the quantum level due to the selective absorption of electromagnetic energy by charged particles in human body cells (e.g., ions) in a magnetic field at frequencies equal to or multiples of their cyclotron frequency [336–340].

The mechanism of magnetic functional reaction of atoms under the influence of electromagnetic fields is described. Magnetic functional reactions of atoms in electromagnetic fields include manipulation of electron spin, induction of magnetic moments, and change in energy levels [287,341,342]. Biological cells and tissues of various organs of the human body have distinct structural features and fundamentally different molecular compositions. Individual quantum-mechanical characteristics of the atoms in each molecule create specific quantum-mechanical conditions in the cells of the corresponding tissues. They are characterized by a unique physical feature: the change in the magnetic moments of electrons and atomic nuclei when interacting with energy from an external electromagnetic field [4,202]. The reaction of the molecules formed by them to an external magnetic field will depend on the class of magnets to which the atoms of various chemical elements belong. In science, three classes of atoms of chemical elements or substances consisting of them are distinguished: diamagnetic, paramagnetic, and ferrimagnetic [343–345]. The molecules of the human body are formed by 99% carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). A total of 60% of this amount is hydrogen (H), and therefore, hydrogen may play an important role in the reaction to changes in external electromagnetic fields in the human body. Hydrogen (H) and carbon (C) are diamagnetic and are magnetized against the external magnetic field. Diamagnetic materials also include silicon (Si), phosphorus (P), sulfur (S), chlorine (Cl), copper (Cu), iodine (I), and bromine (Br). Oxygen (O) is paramagnetic and is magnetized in an external magnetic field in the direction of the field. Paramagnets include sodium (Na), magnesium (Mg), potassium (K), and calcium (Ca) [4]. An increase in the parameters of the external magnetic field causes an increase

in the oppositely directed magnetic moments of elements belonging to diamagnetic and paramagnetic materials, as well as an increase in the precessional effect of oscillations of the electron orbits of individual atoms [287,343]. The different total moments of the atoms that form the molecules of cells in tissues of various organs of the human body can determine their subsequent functional responses to changes in the local electromagnetic field [345].

Another quantum mechanism underlying the biological effects of external electromagnetic fields on the human body is substantiated. It stems from the concepts of the biophoton signaling model of cellular communication [173–175]. As noted earlier, non-chemical interactions in cells and between cells are mediated by a current of biophotons. Biophotons are a coherent magnetic field that is emitted from DNA [140,167] and is subsequently placed as a carrier on an electromagnetic coherent current formed by the biopolymer structures of biological membranes [173,175]. The coherent state of biophotons, in the form of standing waves/solitons, enables them to transfer information patterns without changes or losses between molecules in the liquid-crystalline aqueous environment of the cellular matrix [346–354]. The influence of external electromagnetic fields can have direct and indirect effects on biophoton signaling at different levels (Figure 4).

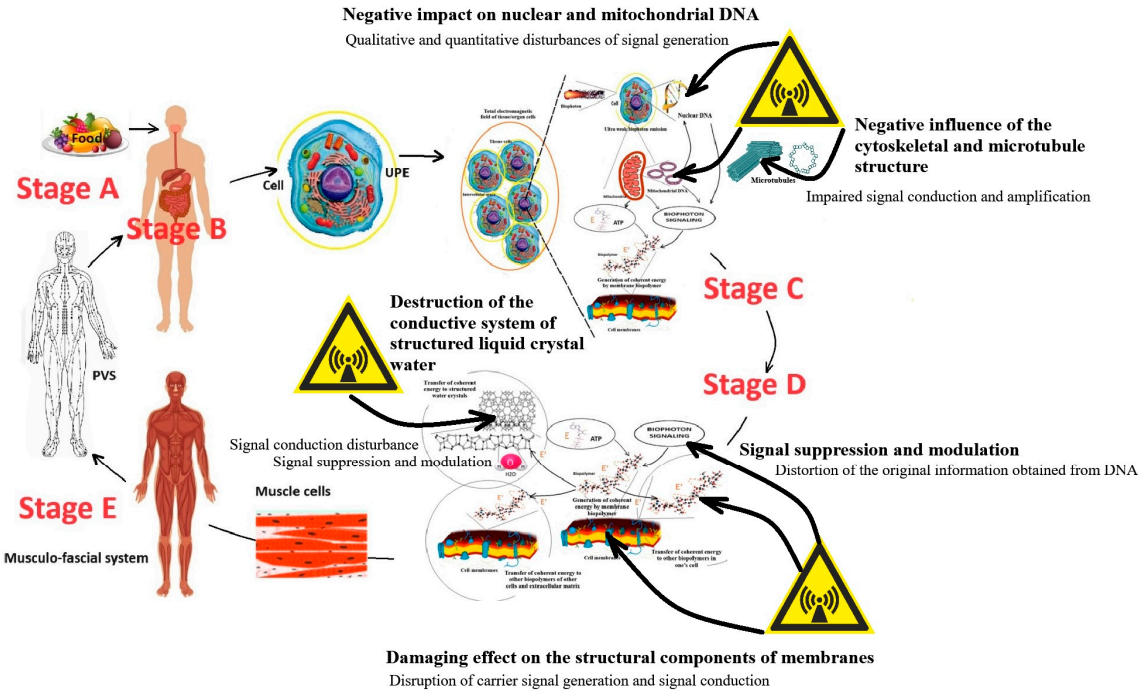

Figure 4. The influence of external electromagnetic fields on biophotonic signaling at different levels. Prospective scheme of energy exchange in the human body, taking into account the working model of the biophoton signaling concept were used [173]. Note: E is the incoherent energy that comes to biopolymers from the universal chemical carrier—the ATP molecule; E′ is the coherent energy that is formed by the oscillatory activity of biopolymers; the yellow circle around the cell is a conventional representation of the UPE phenomenon; the dotted curve is a conventional representation of the oscillation processes of biopolymers. Stage A is the entry of energy in the form of food into the human body. Stage B is the digestion of food, the assimilation of food substrates, and their entry into the blood and cells of the human body. Stage C corresponds to the processes of UPE and tissue respiration in the cell, which lead to the formation of biophotons and a universal energy carrier—the ATP molecule, respectively. Stage D occurs on the biopolymers of membranes of all cells and ensures the transformation of the biochemical energy of the ATP molecule into electromagnetic energy. Stage E is the redistribution and transport of electromagnetic energy from muscles to other parts of the human body through myofascial synkinesis (muscle chains) and PVS. The black arrows emanating from the triangles represent the influence of an external electromagnetic field.

According to the presented promising model scheme [175], biophoton signaling in a cell can be disrupted at five conditional levels: (1) the level of the cell nucleus; (2) the level of mitochondria; (3) the level of intracellular structures and cell membranes; (4) the level of the outer cell membrane; (5) the level of the intercellular space and intercellular interactions.

It is logical that DNA mutations in the nucleus and mitochondria, arising from direct or indirect damage, can lead to pathological changes in biophoton emission, both quantitative and qualitative. Accordingly, abnormal/atypical/pathological information signals from mutated, damaged DNA will enter the cell matrix and cytoplasm. This will lead to changes in its metabolic processes and the appearance of pathological information signals in the quantum electromagnetic fields of the corresponding tissues and organs of the body.

The next variant of biophoton signaling disruption may be associated with direct or indirect damage due to pathological activation of the oxidation of biopolymer molecules in membrane structures. Damage to biopolymers will disrupt the generation and translation of specific coherent electromagnetic currents within the biological cell. Since these electromagnetic currents are carriers of the informational biophoton signal from DNA [174,175], this can lead to their weakening. If this occurs simultaneously with DNA damage, it will be accompanied by a change in the informational quality of the biophoton electromagnetic signal. This will bring corresponding changes to the cellular electromagnetic field and to metabolic and molecular cooperation in vivo. At the intracellular level, direct or indirect free-radical oxidation of cytoskeletal/microtubule structures, as well as of the extracellular matrix, can occur. According to current concepts, these structures participate in biophotonic signaling as channels for amplifying and protecting the transfer of the biophotonic electromagnetic signal from the cell's DNA to distant compartments and to other cells [355–358]. Accordingly, damage to the cytoskeleton/microtubules will disrupt conduction and amplify the electromagnetic signal within the cell and beyond it in organ tissues.

Another variant of disruption of biophoton signaling at the subcellular and cellular levels may be associated with increased destruction of energy-intensive liquid-crystalline water structures. Water molecules structured into liquid crystals assemble into hierarchical, long chains that transmit the biophoton-coherent signal between molecules within the cell and in the intercellular space without loss [351–355]. As a result, the biophoton signal can be transmitted between cells in organ tissues over significant distances [5,6]. Liquid-crystalline water hierarchical chains/structures are in dynamic equilibrium [5,6]: they constantly undergo decay processes due to destruction by radicals and ions, and form new structures under the constant electromagnetic energy supplied by biopolymers. Theoretically, exposure to external electromagnetic fields can activate their decomposition processes, both directly through direct action on water molecules and indirectly through the activation of ions and free radical oxidation. This will reduce the transmission of biophoton signals between molecules within the cell and between cells.

It is important to note that combined/associated damage at the designated levels of formation and conduction of the biophoton signal will have more pronounced negative consequences for the cell, since it will essentially modify, weaken, and interfere with the further transmission of its electromagnetic signal. Since these biophoton signals are of fundamental importance for the normal course of metabolic processes in the cell, for the processes of its repair and morphogenesis, communication and unification into a single morphological functional whole with other cells of the tissues of the body's organs [145,146,356,357], their pathological change and weakening is fraught with a change in the functional state of the cell with relatively minor damage and gross metabolic and morphological changes with severe and long-term increasing damage, up to malignancy and death. This working concept describes universal mechanisms common to all cells of the body. It complements

existing scientific understanding of the causes of cancer by describing a further universal mechanism for the development of pathological abnormalities in cells, driven by external electromagnetic fields. This research should be continued as a promising direction in the future.

Quantum mechanisms underlying the effects of external electromagnetic fields are not limited to the subcellular and cellular levels. Since the living human organism is a complex, multi-level system with numerous micro- and macroscopic processes, quantum mechanisms underlying the effects of external electromagnetic fields can, in principle, be reflected in each of these processes, manifesting clinically at the corresponding level (Figure 2 on the right). This is because the coordination and course of metabolism in the human body are based on electromagnetic processes at the corresponding hierarchical level of its structure [173,175]. At the levels of organs, organ systems, and the entire organism, this coordination is determined by numerous oscillatory processes, beginning with oxidation-reduction reactions in the cell and extending to oscillatory interactions among organs [46]. The body uses oscillatory processes to regulate its activity and is capable of perceiving vibrational information of all types, quickly responding, and adapting to changes in the external environment. From a biophysical point of view, the body is a self-oscillating, nonlinear system, with resonator circuits for the transformation and replenishment of energy, a nonlinear limiter of oscillation growth, and feedback between the resonator and the energy source. A classic example in science of a resonant circuit in the human body and its coupling with external electromagnetic fields is the human skull cavity, with the brain functioning within it as an emitter of electromagnetic signals [46]. The synchronization of electromagnetic wave processes in the brain with the Earth's atmospheric electromagnetic fields at Schumann resonance frequencies has been established [358–369]. This is the mechanism of forced resonance. In this case, a coincidence occurs between the frequency of the forcing effect (e.g., the first harmonic of the Earth's electromagnetic field) and the natural frequency of the system (brain rhythms) [49,370].

Aspects of this synchronization continue to be studied. These mechanisms are grounded in universal physical laws governing the interaction between external electromagnetic fields and the human body. The nervous system has a high signal transmission rate and is responsible for feedback throughout the body. At the organ and tissue levels, feedback is provided by electrochemical processes and mechanical movements in the body's oscillatory systems. Tissues and organs are characterized by numerous electrochemical processes associated with the exchange of electrons and ions, and each has its own frequency-wave characteristics. Therefore, it is logical to assume that all of them, to varying degrees and through various combinations of mechanisms, respond to the local electromagnetic fields of the Earth. Such connections have been established for the cardiovascular system [371–374], the autonomic nervous system [375,376], biologically active points of the skin [377–382], and the urinary system [344,383]. This also requires further study. Various types of magnetoreception represent biological mechanisms in the body.

At the organismal level, the perception of the effects of external electromagnetic fields is associated with the magnetic properties of blood. Blood is a magnetically saturated medium. The magnetic properties of blood are explained by the hemoglobin content of red blood cells, which possess a non-zero magnetic moment due to the iron atoms in their composition. Therefore, external electromagnetic fields can affect blood by altering the distribution of ions and their transport across the human red blood cell membrane. This alters the electrical potential of red blood cells and the depolarization processes of their membrane structures. It has been established that after exposure to an external electromagnetic field, changes occur in the transport of electrogenic sodium and potassium ions in red blood cells, their electrical mobility decreases, the permeability of the outer membrane

increases, and its aggregation properties are activated. Spontaneous magnetization of the particle array in red blood cells due to the parallel orientation of their magnetic moments leads to the formation of groups with ordered packing. When moving through the vascular bed, such a group of erythrocytes behaves like a soliton [381–386]. The formation of such objects in the bloodstream obviously explains the phenomenon of reversible erythrocyte aggregation. When such an object moves through the vascular bed, the parameters of its magnetic flux change with changes in vessel diameter. This, in accordance with the law of electromagnetic induction, leads to the emergence of electric currents that tend to compensate for the changes in magnetic flux. Blood plasma contains a large number of ions. Therefore, it has electrical conductivity. Electric currents induced by moving soliton-like objects from erythrocytes can lead to increased plasma circulation around them. Therefore, this mechanism can influence the general electromagnetic state of organs of the human body with abundant blood circulation and can also induce an indirect biological reaction in them to external electromagnetic fields.

Research results [387,388] confirm the existence of a magnetic sense in humans and the quantum-mechanical mechanism of magnetoreception. For example, it is known that magnetic resonance mechanisms provide light-dependent magnetic orientation in humans. These reactions are mediated by magnetic-field resonance. This confirms the deterioration or enhancement of human navigation ability when using radiofrequency magnetic fields at the Larmor frequency, and the dependence of these effects on the angle between the radiofrequency and geomagnetic fields [387,388].

An important step toward understanding the essence of electromagnetic interactions within the body is the search for the morphological substrate of the human body's electromagnetic receptors. Today, this function is definitively linked to the crystalline structures of biogenic magnetite (Fe_3O_4), which has been identified in brain cells and the highly innervated ethmoid bone of the human skull. Ferromagnetism is a scientifically proven method of sensory transduction [49,276,389].

These crystals have a finely dispersed structure, 0.01–0.1 μm in size, comparable to molecular size, are typical of a crystalline compound in a chain, and are presumably synthesized in the body, since a similar structure has not been identified in nature outside biological systems. Their function is to act as a biological "sensor" at the quantum level. The orientation of biomagnetite crystals in cells maximizes their magnetic moment and ensures a group systemic effect. Presumably, as a result, they can provide sufficient mechanical energy to activate transmembrane ion channels in certain groups of neurons and other cells [70,390,391]. Analysis of the magnetic properties of human tissue indicates the presence of magnetic effects arising from the interaction of groups of biomagnetite crystals, averaging the effects of weak ultraslow magnetic fields in cell membranes [392]. Magnetite biomineralization is believed to be a genetically controlled biochemical process [197]. The fundamental nature of the discovery of biomagnetite-associated magnetoreception and its role as a universal natural function in interaction with EMFs is evident in the presence of similar biomagnetite crystal structures in magnetically sensitive bacteria, insects, and the brains of fish, birds, and mammals, especially migratory animals. However, it has been established that living tissues contain much more biomagnetite than is necessary for bioreception. The biological function of this additional material has not yet been established. At the same time, behavioral experiments with bees and birds using short, intense magnetic pulses have shown that biomagnetite is involved in sensory transduction/transformation of geomagnetic field energy in the nervous system. Ferromagnetic materials in biological systems can provide physical mechanisms for transforming ultraslow magnetic fields into other forms of energy, as well as for generating microwave energy in the frequency range of the ferromagnetic resonance peak—0.5–10 GHz [197]. This raises the question of whether

endogenous biomagnetite is part of the system of "assimilation" of the geomagnetic field by the organism, without which, as has been established, biological life is impossible [70].

According to several authors [52,393,394], the human body responds to external electromagnetic influences through the functioning of a class of ion channels—the versatile gamma-aminobutyric acid (GABA) ion channel (VGIC)—in all cell membranes. VGIC ion channels are present in all cells of plants and animals, including humans [394–396], and function as sensitive sensors of electromagnetic fields. VGICs transition from an open to a closed state when the membrane voltage changes by ≥30 mV, which affects their "voltage sensors." The functional characteristics of VGIC ion channels are described in detail in the review [52].

The magnetic sensitivity of the human body may be associated with the functioning of biologically active points on the human skin. The emergence and integration into the paradigm of new knowledge about the existence [338–404] and functioning [405–412] of the PVS create the foundation for further study and understanding of the principles of electromagnetic reception by biologically active points of the human skin. According to several authors, the PVS is a histomorphological system that transmits an informational biophotonic signal between organs and remote tissues in the body [405–412]. The PVS has bioelectric activity, excitatory conductivity, and mechanical mobility [405–412]. Its functional state/electromagnetic parameters change with the organ's changing needs [173,175,410], and its endings are present at all biologically active points of the skin [173,175,401]. Because the PVS provides non-chemical electromagnetic communication between organs in the human body, biologically active points of the skin can be involved in systemic regulation. This explains the biological significance of the electromagnetic heterogeneity of human skin. The idea that biologically active points can act as magnetoreceptors and respond to external electromagnetic fields is supported by the positive results of reflexology using magnetic and electromagnetic stimulation on the corresponding biological points of the human skin [173,175,413–415]. This requires further study.

Since the human body is a single entity, the three identified mechanisms of interaction between external electromagnetic fields and the body are interconnected and enable complex adaptive responses at the systemic level or locally at the site of exposure. A summary of the mechanisms of interaction between external electromagnetic fields and the human body identified in the theoretical study is presented in Figure 5.

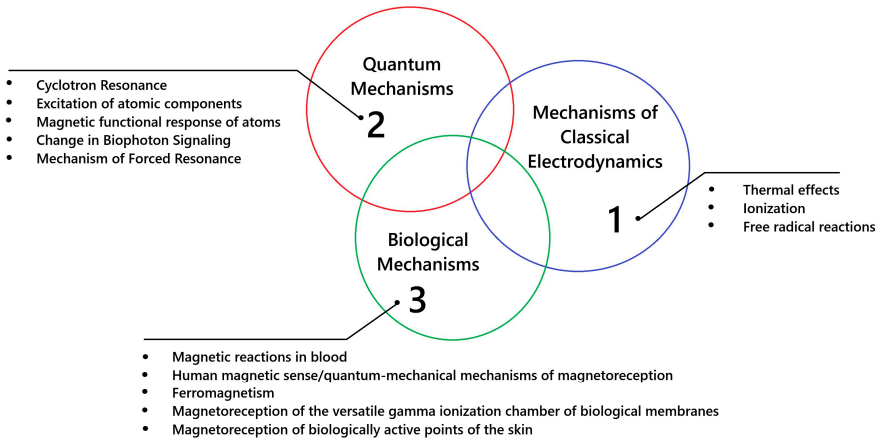

Figure 5. Mechanisms of interaction between external electromagnetic fields and the human body.

3.3.3. Biological Consequences of Electromagnetic Influence on the Human Body

Exposure to electromagnetic fields in the external environment can have both positive and negative consequences for the human body. Positive effects include the creation of basic electromagnetic conditions for biological life through the natural components of the

Earth's electromagnetic field and the synchronization of the human body's endogenous electromagnetic fields with them.

A vast amount of experimental data demonstrates that the effects of cosmic electromagnetic influences are detected at all levels of the biological organization—from single-celled organisms to the neurophysiological processes of the human brain. Cosmic electromagnetic radiation even influences the results of purely chemical or physical laboratory experiments [416–418]. Biorhythmology is important for therapeutic practice, as it has been shown that treatment effectiveness also depends on the timing of its onset [419,420].

The visible spectrum of waves makes the most significant contribution to the natural electromagnetic landscape and enables the main biological effects on the human body. This is because only a portion of the Sun's energy can penetrate the Earth's magnetosphere. Shortwave (ultraviolet, X-ray, and γ-radiation) and longwave solar radiation are almost entirely absorbed by the Earth's atmosphere [421]. The microwave spectrum of electromagnetic radiation is primarily infrared radiation, which reaches the Earth at a lower frequency due to the Doppler effect [422,423].

The effect of solar radiation on the human body can activate its nervous system and metabolic processes [424], among other effects.

Exceptional cases of obtaining positive biological consequences of external electromagnetic exposure include its use of bioactive frequencies for therapeutic purposes [415,425,426]. Since natural electromagnetic fields in the environment are a fundamental condition for the existence of biological life on Earth, a functionally healthy person does not experience sensations or clinically significant biological consequences from these fields. A different situation has been established in people with internal organ diseases/NCDs. It has been scientifically established that their functional state changes in response to the dynamics of changes in the natural electromagnetic fields of the environment. The most common biological consequence in such people is a state of meteosensitivity/meteosensitivity [118]. It has been established that changes in the natural electromagnetic fields of the environment within the Schumann resonance frequency spectrum can destabilize pathological processes in NCDs. For example, they can increase the likelihood of acute coronary syndrome [371], exacerbation of kidney pathology [345,384], and so on.

The adverse biological effects of electromagnetic radiation on the human body are a complex scientific problem that continues to be studied.

Adverse biological effects have been established from excessive exposure to natural frequency components of the Earth's electromagnetic spectrum, including ultraviolet, visible, and infrared radiation. Adverse effects are observed with excessive exposure of the human body to these radiations, and they are dose-dependent. In most cases, these radiations cause adverse biological reactions in the eyes (from symptoms of photosensitivity, lacrimation, pain, damage to retinal proteins to diseases such as photokeratitis, photoconjunctivitis, photochemical damage to the retina, photothermal damage to the retina, climatic droplet keratopathy, pterygium, pinguecula) [427–430] and skin (burns, pathogenetic role in the development of skin cancer) [431–433]. Adverse biological effects on cells of living tissues of human organs arise from the fact that excessive exposure to an external electromagnetic field significantly changes their physico-biological parameters (a decrease in dielectric properties and an increase in conductivity, activation of free-radical oxidation of molecules, denaturation of proteins, etc. are observed) [434]. This causes immediate biological effects in them, and sometimes even irreversible processes if the fields are strong enough. These changes are uneven and depend on the type of tissue, the characteristics of the emitted electromagnetic waves, the environment, and many other factors. These changes can be reversible. In the case of exposure to high-intensity radiation

or to low-intensity radiation above the maximum intensity, they become irreversible. They lead to changes in the structure and appearance of tissues and organs of the human body, burns, hemorrhages, changes in cellular structure, disruption of the nutrition of tissues, organs, or the organism as a whole, and to the death of tissues and/or the organism as a whole [274,435–437].

However, the human body is adapted to exist within the Earth's natural electromagnetic landscape. Therefore, the negative biological consequences of exposure to natural components of Earth's electromagnetic landscape are relatively minor compared to those of anthropogenic electromagnetic radiation. Therefore, the scientific study of the adverse biological effects of electromagnetic influences on the human body has become a pressing issue since the beginning of our civilization's technological mastery of electromagnetic energy and its widespread, active use. Modern fundamental science has uncovered the reason why this is so. It has been established that anthropogenic electromagnetic fields and the corresponding electromagnetic radiation are generated by electrical/electronic circuits/antennas with specific geometric shapes and are fully polarized, coherent, oscillating, and highly variable at any given moment, especially in intensity [52]. These parameters make them fundamentally different from natural electromagnetic fields and closer in their physical characteristics to the endogenous millimeter-range electromagnetic radiation of biological cells, which is why they exhibit pronounced bioactivity [52]. Unlike anthropogenic electromagnetic fields, natural electromagnetic fields are polarized and coherent but more static, with less sharp variability (characterized by longer cycles).

Polarization, coherence, variability, significant intensity of radiation with total electric and magnetic fields, proximity to the millimeter biological range of radiation, cause a significantly pronounced effect on the components of biological cells in vivo and make all anthropogenic electromagnetic fields significantly more unfavorably biologically active than natural electromagnetic fields [437–440]. This has been proven in studies that confirm that modulated (especially amplitude-modulated) or pulsed radiofrequency electromagnetic fields are significantly more bioactive than unmodulated or non-pulsed fields of the same carrier frequency and the same intensity as pulses [437,441–463]. Moreover, the biological effects established in all rays were "non-thermal". This suggests that the biological effects of electromagnetic fields in the optical range are due to the inclusion of low-frequency radiation pulsation/modulation [52]. The most pronounced oscillation effects and substantial intensity variability are observed in electromagnetic fields generated by wireless communication devices/antennas (including relevant base stations, mobile and cordless phones, Wi-Fi routers, Bluetooth connections between electronic devices, etc.). These are low frequency electromagnetic fields (WC EMFs), which consist of microwave (MW) carrier waves (300 MHz–300 GHz) modulated by extremely low frequency (ELF: 3–3000 Hz) or very low frequency (VLF: 3–30 kHz) signals and included in on/off pulses repeating at different ELF frequencies with intense random variability in signal amplitude depending on the frequency in the ultra low frequency (ULF: 0–3 Hz) range [52]. Also, all anthropogenic digital emitters of "Radiofrequency Electromagnetic Fields" (RF EMFs) (radars, television and radio broadcasting systems) contain low-frequency pulsations [440,464–467]. According to research results, it is the ultra-low-frequency electromagnetic fields themselves that exhibit bioactivity, and they are responsible for the non-thermal/quantum effects of near-spectrum electromagnetic fields [452,468–485]. This occurs due to the proximity and identity of their biological range to the biophotonic communication of cells in vivo [4]. All this makes these sources of anthropogenic electromagnetic radiation the most bioactive and, accordingly, the most capable of influencing endogenous electromagnetic processes in biological cells *in vivo*.

This is confirmed by the results of studies of the influence of artificial electromagnetic fields of low or ultra-low frequency on laboratory animals or biological cells, in which adverse biological effects were established in the form of such pathological events as activation of oxidative stress and accelerated aging [486–495]; damage/mutations of DNA, chromosomes, loss of replicative activity [218,448,449,471–479,496–551]; death of cells of the reproductive system or embryonic death after DNA damage in spermatozoa of mice or rats [497,534], ovarian cells of fruit flies [501,524,525], human spermatozoa [503,504] in quail embryos [501,550]; a significant decrease in reproductive function (decreased egg production, decreased development of reproductive cells, or death of embryos) in fruit flies [524,525,552,553], in chicken or quail embryos [500,550,554], in cattle oocytes [555], in birds [556–558], in bees [559], in amphibians [560–562], in rats and mice [534,547,562–564], in human sperm (decreased sperm count and motility) [37,565]; infertility in insects, birds, and mammals (including humans) [37,121,552,553,559,562–568], abortions [569], or declines in bird and insect (especially bee) populations over the past 20 years [214,556–559,569]; increased DNA damage (strand breaks) in the brains of irradiated animals [570]; genotoxic effects [489]; cancer [571,572], including brain cancer (glioma) and heart cancer (malignant schwannoma) in rats [573,574]. For these reasons, Extremely Low Frequency (ELF) and Wireless Communication (WC) Electromagnetic Fields (EMFs), commonly referred to as "RF," are classified as possibly carcinogenic to humans (Group 2B) by the International Agency for Research on Cancer (IARC) [575–577]. Global System for Mobile Communications radiation triggers seizures and increases cerebral c-Fos positivity in rats pretreated with subconvulsive doses of picrotoxin [578].

Epidemiological studies have confirmed a link between exposure to microwave antennas/devices and symptoms of illness (asthenia, headaches, fatigue, sleep disturbances). This has been termed "microwave syndrome" or "electrohypersensitivity" [579–590]. Studies have linked the onset of these symptoms to increased ambient levels of radiofrequency electromagnetic fields following the introduction of 5G mobile communications [591,592].

3.4. Problems and Prospects

The main problems and prospects identified during the theoretical study are shown in Figure 6.

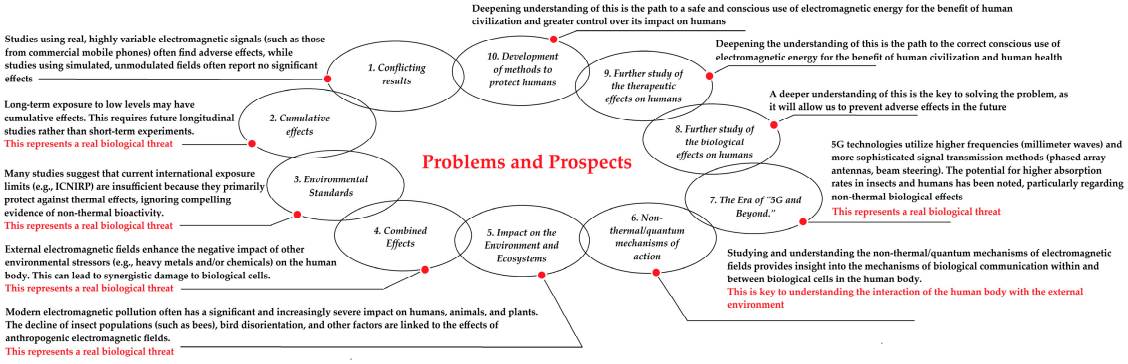

Figure 6. Main problems and prospects of research in the field of "Human Bioelectromagnetism and the Environment".

Currently, as anthropogenic electromagnetic radiation increasingly contributes to Earth's local electromagnetic landscapes, the interaction of electromagnetic fields between the human body and the external environment is a serious issue in electromagnetic ecology. This is an interdisciplinary and transdisciplinary problem that must be addressed simultaneously in several areas: medical, biophysical, biomedical, scientific and technical, and pedagogical. Medical scientists must intensify their study of the adverse effects of

anthropogenic electromagnetic radiation on the human body, including its mechanisms. A clear, medical-scientific position developed by the medical academic community should serve as the basis for societal decision-making and the development of policies for the regulated, safer use of electromagnetic energy in support of humanity's needs. Biophysicists and biologists should continue their research into the interactions of different types of electromagnetic radiation with the biological tissues of living organisms, including humans. This should serve as the basis for optimizing the regulation of the effects of electromagnetic fields on the human body at this stage. There is a need to develop improved methods and tools for analyzing electromagnetic fields in the environment, as well as means to protect against their negative impacts. To date, humanity has not fully grasped the extent of the problem posed by the detrimental impact of anthropogenic electromagnetic radiation on itself and all forms of biological life. Therefore, it is necessary to update the educational sector's work and conduct extensive scientific and educational outreach across all segments of the population on the need for proper, safe, and regulated use of mobile phones, computers, and other devices.

The growing body of scientific evidence on the hazardous effects of anthropogenic electromagnetic fields on the human body has led to a shift in scientific opinion. A growing number of scientists are raising the issue of the current need to reassess the biological impact of Extremely Low Frequency and Wireless Communication Electromagnetic Fields (EMFs), commonly referred to as "RF," and classify them as probably carcinogenic (Group 2A) or carcinogenic (Group 1) to humans [422,488,544–546,591–597]. Many scientists are also calling for stricter electromagnetic safety regulations and requirements in living spaces, a moratorium on further 5G deployment, the urgent application of the precautionary principle, and stricter exposure limits, especially for Wireless Communication Electromagnetic Fields [422,489,556,598–600]. As demonstrated by the data in this review, electromagnetic processes are key to the functioning of the human body. Therefore, electromagnetic energy can be used for therapeutic purposes in complex treatment and maintenance of human health. The effectiveness of these approaches is confirmed by the advances in the medical field of "Bioelectronic Medicine" [601–605]. The use of bioactive frequencies for therapeutic and preventive purposes could, in theory, become a component of a comprehensive approach to mitigating the adverse effects of anthropogenic electromagnetic fields on the human body.

A promising option for effectively combating anthropogenic electromagnetic pollution may be the use of biogenic electromagnetic radiation to shield human habitats. Increasing the number of green spaces (trees, shrubs, etc.) can help protect humans from the negative effects of anthropogenic electromagnetic fields. Scientific interest in developing materials for electromagnetic wave absorption remains high. Along with traditional magnetic absorbers (e.g., ferrites and metal powders), carbon-containing and metal–organic framework-derived materials have emerged as promising candidates for electromagnetic wave absorption [606,607].

4. Discussion

In fact, at the current stage of scientific research, the influence of natural and artificial electromagnetic fields on biological systems and the human body has been established. Currently, scientific thought is focused on developing hypotheses about the mechanisms underlying magnetobiological effects and their role in biological systems. Also, an undeniable, logical, and obvious fact is the connection between the human electromagnetic field, metabolic activity, and functional state. However, the nature of these relationships requires further study. The endogenous electromagnetic fields of living organisms and humans, as objective realities and links in a single natural energy chain, are of scientific and practical

interest for further understanding the fundamental issues of human body functioning. The growing relevance of studying the interactions between external electromagnetic fields and endogenous human electromagnetic fields is dictated not only by the need to understand the biological aspects of living systems and the potential use of exogenous electromagnetic fields in instrumental diagnostics, but also by the undeniable fact that the emergence of artificial electromagnetic fields undoubtedly impacts human health and the pathogenesis of diseases. This issue is currently pressing and requires increased attention from medical scientists and the modern healthcare system. Furthermore, understanding the mechanisms of electromagnetic field action on biological organisms can contribute to the optimization of treatment by introducing fundamentally different methods for influencing the human body through frequency waves and other therapeutic methods. Thus, given the fundamentalism, universality, and unity of energy exchange mechanisms in the natural chain and an understanding of the inextricable connection between the human body and these mechanisms, modern medical science should no longer ignore these issues.

This perspective review systematically summarizes current scientific data on "Human Bioelectromagnetism and the Environment." This was carried out to strengthen transdisciplinary dialogue among scientists from various fields for further study of the interaction between the electromagnetic fields of the human body and those of the external environment. From the material in Section 3.4 of this perspective review, it is clear that solving the current problems in this area and shaping public understanding require the unification of scientific minds, the efforts of scientists from many fields, and the consolidation of the entire academic community. Therefore, this perspective review presents, for the first time, scientific data that extrapolate aspects of the working concept of biophoton signaling [173–175] to the existing understanding of the mechanisms by which external electromagnetic fields influence the human body. Moreover, this material requires active scientific discussion. Here is why.

This concept significantly deepens and complements existing understanding of the mechanisms of electromagnetic field action at the quantum level. It reveals the concept and mechanisms underlying endogenous electromagnetic communication in the human body. This communication occurs in the millimeter range via the transmission of endogenous coherent biophoton radiation through biopolymer molecules, water structured into liquid crystals, and the cell matrix cytoskeleton. These coherent electromagnetic currents, generated by the biopolymer molecules of membrane structures, carry information patterns in the form of solitons/polaritons and contain information content from the cell's DNA molecules. The endogenous cellular electromagnetic field generated by these processes forms an informational quantum electromagnetic matrix that ensures constant access to information and energy for all molecules in the cell. This ensures the coordinated, simultaneous flow of all biochemical reactions in the cell, coordinated protein folding, and coordinated morphogenesis processes according to the genetic information entering this field in the form of biophoton emission from DNA. What happens when exposed to anthropogenic electromagnetic fields? Theoretically, they can affect all stages and levels of biophoton signaling in cells and modulate or distort it at all levels. This will lead to its weakening and distortion of its informational component. Depending on the degree and nature of this distortion, the biological consequences will include disruptions in the course of biochemical metabolic reactions and vital processes in the cell. Secondly, they can damage DNA, causing mutations, and thereby alter the quality and intensity of biophoton emission from DNA. The consequence of this will again be changes in the cell's metabolism and vital processes. Third, they can damage microtubules, the matrix's cytoskeleton, and disrupt the ordered state of liquid water crystals. This will further deteriorate the quantitative and qualitative parameters of biophotonic electromagnetic signal transmission. This will

again result in disruptions to metabolic processes and cellular vital functions. As a result, biological cells experience destruction/damage to the informational component of their regulation. This blocks cellular vital functions. The maximum manifestations of these disruptions are disruption of cell reproduction, malignancy, and death. Therefore, the concept of biophotonic signaling logically explains, from a biological perspective, the pathogenesis of infertility, cancer, and other adverse biological consequences of electromagnetic exposure to the human body, as outlined in Section 3.3.2.

This certainly requires further theoretical research. However, it is a viable scientific concept that provides a logical, working biological explanation for the processes occurring in cells exposed to external electromagnetic fields. On the one hand, this concept substantiates the importance of non-chemical electromagnetic communication/biophotonic signaling in cells. On the other hand, it demonstrates the seriousness of the pathogenic effects of anthropogenic electromagnetic fields and their biological threat to the human body. Thus, this is a fundamentally important starting point for further scientific research and the search for a solution to this problem.

In terms of scientific discussion, the logical question is: why has not all of humanity yet experienced the adverse biological consequences of electromagnetic exposure in recent years? Indeed, as noted earlier, the occurrence of adverse biological consequences depends on a combination of many factors associated with both the radiation parameters and the functional state of the human body. From the perspective of the working concept of biophoton signaling, the following biological explanation can be given. In the body, along with the "open" transmission of the biophoton signal through the molecular structures of the cytoplasm and membranes, there is a "closed/protected" transmission, which is obviously realized at the cellular level through the microtubules of the cytoskeleton [173,174], and at the tissue and organ level occurs through the PVS channels [173,175]. Because PVS channels are protected and apparently do not transmit electromagnetic signals through their walls, and because they contain free DNA in their fluid to maintain an electromagnetic signal specific to the body [173], cells and tissues can survive longer and maintain their physiological activity in an unfavorable electromagnetic environment. This is still just a hypothesis. There are valuable new ideas here that should be made available to a broader audience within the academic community across all specialties. Existing scientific data on PVS should be reconsidered and integrated into the modern scientific paradigm. Research in this area should be continued.

The discovery of electromagnetic mechanisms for energy and information transfer in biological cells, using biophotons, demonstrates the possibility of previously unknown interactions between the human body and external electromagnetic fields, through the potential influence of endogenous biophoton signals. This is an important and promising area of scientific research for furthering our understanding of the fundamental mechanisms of interaction between the human body's endogenous electromagnetic fields and those of the external environment. This also opens new avenues for understanding the pathogenesis of internal organ diseases/NCDs. Disruption of non-chemical/electromagnetic communication between organs can undoubtedly be another cause of comorbidity and combined organ damage in NCDs. Therefore, increased anthropogenic electromagnetic influence may be an additional pathogenetic factor in the development and progression of chronic internal organ diseases. Further research in this area is necessary.

Research into the information component of electromagnetic radiation/biophoton signals from human cells in vivo, and the mechanisms underlying their redistribution between organs, is a promising future direction. This is important to note in light of the topic of this review because it opens a fundamentally different perspective on the mechanisms of interaction between the electromagnetic fields of the human body and the

external environment. According to these modern concepts, the interaction of external electromagnetic fields with the internal fields of the human body can occur at relatively low levels of irradiation due to the resonant nature of non-thermal exposure at frequencies close to the natural vibration frequencies of biological molecules and supramolecular systems. In this case, the effect of electromagnetic fields is informational. It influences the functional state of cells by interfering with endogenous electromagnetic processes of energy and information transfer/biophoton signaling of their metabolism and vital functions.

Research into the biomagnetism of the human body is directly related to the study of electromagnetic processes in the brain, higher nervous activity, and their interactions with external natural electromagnetic fields (e.g., Schumann resonance frequencies). Currently, the study of these aspects raises more questions than answers. However, modern scientific progress and the hope for trans- and interdisciplinary collaboration among scientists in the future give hope that scientific interest in the study of human biomagnetism will be renewed and receive comprehensive support.

5. Conclusions

Based on the analyzed scientific data available through literature search, the following can be stated: (1) There is a proven interaction between the human body and external electromagnetic fields (natural and anthropogenic). (2) The human body is a component of the Earth's electromagnetic landscape and has biophysical mechanisms for coupling with it. (3) The development of human civilization has led to the active use of electromagnetic energy with the creation of a large number of anthropogenic sources and to a change in the Earth's electromagnetic landscape. (4) Anthropogenic electromagnetic radiation has fundamental differences from the natural electromagnetic background of the Earth and has a proven negative impact on the human body. (5) At present, anthropogenic electromagnetic radiation is a serious problem in electromagnetic ecology. (6) To solve the existing problems of electromagnetic ecology, a transdisciplinary consolidation of scientists is necessary for further study of safety issues and the impact of anthropogenic electromagnetic fields on the human body. (7) Such measures as re-evaluation of the biological impact of Extremely Low Frequency and Wireless Communication Electromagnetic Fields, classification of them as probably carcinogenic (Group 2A) or carcinogenic (Group 1) for humans, tightening of electromagnetic safety standards and requirements in places of human habitation, a moratorium on further deployment of 5G, urgent application of the precautionary principle, stricter exposure limits, especially for Wireless Communication Electromagnetic Fields are necessary. (8) Further study of aspects of biomagnetism of the human body is a relevant and promising transdisciplinary scientific direction of fundamental science, which is associated with future discoveries in understanding the essence of human life and health.

Author Contributions: Conceptualization, G.N., G.J., M.P., O.M., and A.V.; Data curation, G.J. and A.V.; Formal analysis, O.M. and A.V.; Investigation, G.N., A.V. and M.P.; Methodology, A.V., G.J., and O.M.; Project administration, A.V.; Resources, G.J.; Supervision, A.V. and G.J.; Validation, G.J., and A.V.; Visualization, G.N.; Writing—original draft, G.N.; Writing—review and editing, G.J., M.P., O.M., and A.V. All authors have read and agreed to the published version of the manuscript.

Funding: The theoretical study was carried out in conjunction with the following scientific institutions: (1) Lithuanian University of Health Sciences, Lithuania (the cooperation coordinator is prof. G. Jarusevicius and prof. A. Vainoras); (2) Poltava State Medical University, Ukrainian (the cooperation coordinator is prof. M. Potyazhenko); (3) Shupyk National Healthcare University of Ukraine (the cooperation coordinator is prof. O. Mintser; the study is a fragment of research work of the initiative international study of the Earth's magnetic field using the Global Coherence Monitoring System (GCMS)). The study is a fragment of research work of the Laboratory for Automatization of

Cardiovascular Investigations, Cardiology Institute, Lithuanian University of Health Sciences. This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We wish to thank Lithuanian University of Health Sciences for supporting research on the influence of the Earth's magnetic field on the human body.

Conflicts of Interest: The authors declare no conflicts of interest.

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