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Biofield Science: Current Physics Perspectives

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ABSTRACT

This article briefly reviews the biofield hypothesis and its scientific literature. Evidence for the existence of the biofield now exists, and current theoretical foundations are now being developed. A review of the biofield and related topics from the perspective of physical science is needed to identify a common body of knowledge and evaluate possible underlying principles of origin of the biofield. The properties of such a field could be based on electromagnetic fields, coherent states, biophotons, quantum and quantum-like processes, and ultimately the quantum vacuum. Given this evidence, we intend to inquire and discuss how the existence of the biofield challenges reductionist approaches and presents its own challenges regarding the origin and source of the biofield, the specific evidence for its existence, its relation to biology, and last but not least, how it may inform an integrated understanding of consciousness and the living universe.

INTRODUCTION

Conventional biology is based on molecular processes—ie, biochemical interactions that ultimately reduce to macromolecules such as DNA and RNA. Even organismal biology, which concerns itself with addressing organisms as wholes, still relies on the reductionist approach of understanding the whole by analyzing how the parts fit together. These approaches, although very successful in specific scientific and medical applications, fail to address phenomena that by their nature are holistic—ie, they may need to be explained from a whole organism context, crossing boundaries of scale, and thereby including quantum and conventional fields, mind, and relationship to environment. It seems that biology, despite the great successes it has achieved and the multitude of applications in theory as well as in practice, has still not undergone the types of revolutions that shook physics over the last 100 years.

Evidence for the existence of the biofield now exists, and current theoretical foundations are now being developed.[1,2] The term *biofield* describes "a field of energy and information, both putative and subtle, that regulates the homeodynamic function of living organisms and may play a substantial role in understanding and guiding health processes."[3] Another definition describes it as

> *an organizing principle for the dynamic information flow that regulates biological function and homeostasis. Biofield interactions can organize spatiotemporal biological processes across hierarchical levels: from the subatomic, atomic, molecular, cellular, organismic, to the interpersonal and cosmic levels. As such, biofield interactions can influence a variety of biological pathways, including biochemical, neurological and cellular processes related to electromagnetism, correlated quantum information flow, and perhaps other means for modulating activity and information flow across hierarchical levels of biology.*[4]

Unified and coherent characteristics of the biofield imply a strong and perhaps unique role for quantum models. A review from the viewpoint of physical science is needed in order to identify a common body of knowledge and evaluate possible underlying principles of origin of the biofield. To that end, the review presented here surveys current models including electromagnetic processes and quantum models. We go on to speculate on processes that are not currently well understood. Central to the possible role of quantum theory, for example, we discuss quantum biology and its manifestations in such processes such as photosynthesis, avian navigation, olfactory reception, regeneration, microtubule interactions, brain dynamics, and cognition.

It has been hypothesized that biology could ultimately be built from more fundamental underlying quantum physics. This assumption is implicit in many approaches to molecular biology, genetics, and various applications in medicine and health but is often more honored in the breach. If biology truly derives from physics, then biology should be an extension of quantum physics, the most accurate and fundamental physical theory at our disposal. While quantum biology is an emerging branch of science, most practicing biologists don't take it into account. Conventional biology and biophysics derive predominately from a biochemical and Newtonian physics standard, but biological effects

that cannot be understood without reference to quantum phenomena are accumulating, as in avian magnetoreception, olfaction, and plant photosynthesis.

However, very recent work[1] describes a theoretical foundation for biology, suggesting that biology can be put on an equal footing with physics and not simply reduced to biochemical processes. Living matter would then be seen as following basic principles and laws that are not reducible to conventional physics, though would be smoothly interwoven with quantum physical processes. In this view, we would assert that the generic science of biology is complementary to the generic science of physics (ie, the 2 are closely related but not identical). Possibly both are anchored to mutual processes through the underlying quantum vacuum.

In this regard, the evidence for the existence of the biofield holds the promise of significant growth in scientific understanding and for developing applications in medicine, health, and healing. This line of research and application of quantum physics perspective approaches living organisms through "an emergent and potentially all-encompassing biofield"[2] that entails the existence of long-range interactions, most likely of a coherent nature. Even as experimental evidence is accumulating for the existence of precisely such a long-range, coherent biofield, theoretical understanding is still lacking. Various hurdles exist: The concept of the biofield has many aspects, the concept often means different things to different workers, and a clear language for the description of biofield interactions hasn't been agreed upon. Further complicating the situation is that a host of relevant terms and concepts (eg, bioplasma, bioelectromagnetics, quantum vacuum) are being widely used in a variety of different contexts.

Does the theoretical understanding of biofield involve a few dominant theories? Do they depend on specific phenomena? Can such understanding be part of existing field theories (such as electromagnetism) or is new physics a necessary outcome of studies of the biofield? From the viewpoint of classical physics, another possibility that has been suggested is that the biofield consists of electromagnetic emanations from molecular transitions in living matter. This possibility is not viable due to associated short timescales. From this perspective, electromagnetic field (EMF) coherence might be an essential requirement for biofield interactions to organize biological processes.[5] Because quantum physics underlies all electromagnetic theories and thus biochemistry and neurobiology, quantum mechanical processes, the role of the vacuum, and interpretations concerning the role of the mind itself[6] are important aspects to consider. Also we shall discuss in greater detail below how other "quantum-like" properties of the biofield may play a key role in biofield interactions (by *quantum-like*, we intend macroscopic and biological correlates of quantum phenomena such as nonlocality, superposition, complementarity,[7,8] etc). If the workings of generalized, mesoscopic (molecules to mm in size) and macroscopic quantum-like processes that span both physics and biology can be demonstrated, then we will discuss in this article how the biofield itself may be an important—and perhaps to-date, crucial but ignored—missing link. In other words, if *quantum-like* is defined as the more general framework embracing biology and physics, then macroscopic quantum processes such as entanglement (where multiple objects exist in the same quantum state and so are linked together) and coherence (ordering of the phase angles between the components of a system in a quantum superposition) across a single organism and beyond would be crucial signposts marking what lies ahead, coherence as such being a bridge between micro- and macroscales.[9,10] The recent discovery of macroscopic entanglement in 2 diamond crystals could also be pointing to the likelihood that quantum-like phenomena may, in some cases, literally be propagation of quantum level phenomena into the macroscopic scale.[11] These recent issues will be briefly addressed in the current work.

Ultimately, for any quantum discussion, the problem of observation *à la* von Neumann arises.[6] The so-called "von Neumann cut," or the point of separation between the observer and the observed system, suggests an essential role for the observer with clear relevance to how biofield interactions may be connected to brain structure and processes. Where is the observer situated, in the brain? What is the role of mind and consciousness itself in biofield interactions? One can speculate on the many possibilities that exist with regard to the interaction of an observer with observed systems, where the cut may be (if anywhere) in biological systems, serving as a connection to the activity of the biofield. We must consider consciousness as an integral part of biofield theory and experimentation, as any discussion of quantum biology directly implicates the question of the observer and the observer requires consciousness.

The review presented here is meant as a comprehensive introduction to many aspects already known while also highlighting issues remaining and speculating upon conceptual developments that are needed to develop a theoretical framework for the copious body of data on biofield phenomena. We also refer the reader to the extensive discussion presented in the excellent compendium of relevant works in Popp and Beloussov.[12] This book discusses in detailed chapters the idea of biophysics as being quantum biological, developmental biology and morphology and field theory, biophotonic emission studies, mitogenetic radiation as a biofield phenomena, and life and consciousness as relevant aspects to biophysics and integrative biophysics as being inclusive of this.

HISTORICAL AND THEORETICAL CONCEPTIONS FOR THE BIOFIELD

The concept of a biofield has been emerging steadily, with the work of several groups indicating that part of a living organism's energy is "integrated into a sort of an all-inclusive, long range and to a certain degree *coherent field*."[2] This suggests that fundamental properties

like coherence, integrative function, and various long-range influences on the organism are all potentially associated with the biofield. A number of scientists have historically proposed that a biological field exists in a holistic or global organizing form.[13-15] The details are different, but in general, such propositions involve coherence in electromagnetic waves,[15] biophotons,[16] or going beyond electromagnetism, human intention.[17] In some suppositions, an "electromagnetic body" or "subtle body" is invoked, as related to acupuncture meridians in traditional Chinese medicine[18] and chakras, the subtle energy centers in the Indian esoteric tradition.[17] As Liboff notes, "Once the organism is described as an electromagnetic entity, this strongly suggests the reason for the efficacy of the various electromagnetic therapies, namely as the most direct means of restoring the body's impacted electromagnetic field to its normal state."[19]

From a recent perspective, the term *biofield* was coined in 1994 by a panel on manual medicine modalities convened at the National Institutes of Health (NIH) to discuss complementary and alternative medicine (CAM).[20] As result, the NIH, through the National Center for Complementary and Alternative Medicine, issued a request for applications for grant proposals to study a variety of biofield therapies, including Reiki, healing touch, qigong, and other subtle energy healing interactions.[15] As a result of this research focus, much of the physiological evidence for the biofield has come through the application of various CAM techniques of healing.

To get at its nature in terms of fields explored in classical physics, the biofield has been defined as "the endogenous, complex dynamic EMF resulting from the superposition of component EMFs of the organism that is proposed to be involved in self-organization and bioregulation of the organisms."[15] A classical electromagnetic-based definition such as this one can serve as an important starting point, insofar as it involves the concept of bioinformation.[15] However, as we will see below, any electromagnetic-based definition is limiting, since it does not encompass quantum and holistic effects. EMF theories are also themselves special cases of quantum field theories, the latter being more natural and general, and therefore able to account for the properties of coherence, nonlocality, and entanglement,[21,22] which are strikingly relevant to living organisms.

METHODOLOGICAL ISSUES: "INTEGRATIVE BIOPHYSICS"

Before turning our attention to the specifics of the biofield and the underlying physics, we will examine the general role of "integrative biophysics," a term coined by Popp and Beloussov that refers to different aspects of nonconventional biophysics and biology.[12] Specifically, the term indicates a departure from equilibrium thermodynamics, the foundation of classical physics and chemistry[23] on which most of biology is based. Instead, a central aspect of integrative biophysics is modeling of the organism built completely upon the field concept—this forms a common thread throughout integrative biophysics and phenomena associated with biophotons.

> *Quantum mechanics has established the primacy of the unseparable whole. For this reason, the basis of the new biophysics must be the insight into the fundamental interconnectedness within the organism as well as between organisms, and that of the organism with the environment. This will be an integral biophysics. . . . The existence of a prephysical, unobservable domain of potentiality in quantum theory, which forms the basis of the fundamental interconnectedness and wholeness of reality and from which arise the patterns of the material world, may provide a new model for understanding the holistic features of organisms, such as morphogenesis and regeneration, and thus provide a foundation for integral biophysics.*[12]

As a starting point, evidence of bioelectromagnetic fields and the biological effects of external EMFs have historically lagged behind the successes of biochemistry, resulting in a delayed start in understanding the ubiquitous nature of biofields in living organisms. The historical emphasis on reductionist molecular biological explanations has been practical and allowed for the gains of current biomedicine. Organismal and biofield biology and their multifaceted mechanisms and forms may also offer a host of useful approaches for investigating and unlocking the mysteries of life that have been neglected.

The need for general principles in biology has been pointed out by Bizzarri, Palombo, and Cucina[24] and by Grandpierre, Chopra, and Kafatos.[1] Instead of looking on a more integrated approach like systems biology as merely an extension of molecular biology, these investigators strongly suggest that integrated biology and biophysics operate beyond the reductionist approach. For example, these authors are challenging genetics as being the sole discipline for explaining evolution. We hope that integrative biophysics and associated field processes, including EMFs, biophotons, and possible quantum interactions, will soon be seen as necessary, fundamental, and complementary aspects of molecular biology and biochemistry. New vistas for understanding evolution will emerge when these complementary approaches are accepted.

ELECTROMAGNETIC FIELDS

We now turn our attention to specific aspects of biofield, beginning with EMFs. An EMF is a physical field produced by electrically charged particles in motion. We refer to the work of Jerman, Leskovar, and Krašovec[2] for many of the details. A widely applicable notion of the biofield is associated with endogenous EMFs of organisms.[5,2] Every living cell membrane "has

an electric field of very high intensity (around 10^7 V/m) though of a rather low voltage . . . one of the basic features of life."[2] Biomedical researchers and clinicians routinely gather meaningful data from the manifestations of endogenous EMFs through the use of skin surface measurements like electroencephalograms (EEGs) and electrocardiograms (ECGs).[25] The human body also includes classical acoustic energy fields due, for example, to muscular contraction.[26] Coherence is often observed in EEG, which would indicate self-organizing systems.[27] Such coherence has been shown to increase during meditative states of settled awareness.[28,29]

Applying very–low power coherent EMFs at specific frequencies in the mm range to biological systems results in a resonance-like behavior that supports the theoretical prediction of polar coherent modes in a manner comparable to Bose condensation.[30] Polar coherent modes are predicted to result from the high-intensity field across cell membranes, that when driven by metabolism, create coherent microwave oscillation. A Bose-Einstein condensate is a state of matter of a dilute gas of bosons cooled to temperatures very close to absolute zero. Under such conditions, macroscopic quantum phenomena become apparent. Such macroscopic quantum phenomena are hypothesized as qualities of the biofield. Moreover, according to Fröhlich,[27] these polar coherent modes represent the basis for electromagnetic oscillations at cellular levels in the organism. The existence of endogenous EMFs at the predicted Fröhlich frequencies has not yet been proven experimentally, and their coherent nature in the body is only inferred.[2] However, the discovery of an endogenous EMF at much lower MHz frequencies in microtubules is significant because it suggests a form of coherent electromagnetic activity that may play a role in biofield signaling, thus lending some support to the theory coherent modes of Fröhlich but at much lower frequencies than predicted theoretically.[31]

Other indirect indications of endogenous EMFs come from biophotonics,[2] with foundations in the pioneering work of Popp and collaborators on coherent ultraweak light emissions from cells.[12,32-34] Bischof describes the biophoton field,[35] summarizing 90 years of peer-reviewed published research, as follows: "All living organisms, including humans, emit a low-intensity glow that cannot be seen by the naked eye, but can be measured by photomultipliers that amplify the weak signals several million times and enable the researchers to register it in the form of a diagram. As long as they live, cells and whole organisms give off a pulsating glow with a mean intensity of several up to a few ten thousand photons per second and square centimeter," also known as "cellular glow" or "ultraweak bioluminescence."[34] These biophotonic phenomena could point to long-range interactions between biological organisms. This possibility is supported by observations of intercellular signaling mediated by biophotons.[36-39] via a field containing coherent states[32-34,40] in agreement with the pioneering conjectures of Fröhlich.

In summary, the electromagnetic basis includes the presence of at least 2 field sources: "one (static electric-transmembrane potential) that has been known for long, and the other, a high frequency oscillating and more or less coherent EMF."[2] The latter can be considered to have 2 further aspects manifesting in different energy or frequency ranges: (1) a microwave to MHz and lower frequency range coherence, which we can simply refer to as the Frölich field, and (2) a visible/infrared/near ultraviolet diffuse field, which we can refer to as the Popp photon field. The former has been observed but at lower frequencies than predicted; the latter is supported empirically by observations of the statistical coherence of biophotons, which produce emission spectra that are distinctly different from byproducts of biochemical reactions.[40] This appears to be related to quantum mechanical squeezed states.[40,41] Squeezed states of light belong to the class of nonclassical states of light and indicate quantum coherent states. As such, quantum mechanical effects are clearly indicated through coherence and squeezed states in both the Fröhlich and Popp fields; therefore, they constitute nonclassical fields with their own particular properties (see next section). Recently it has been suggested that the Fröhlich field and the Popp field are interconnected through strong mode coupling in living systems.[2] An experimental and theoretical basis for defining the existence of a macroscopic coherent quantum system in living things is being developed here and extended subsequently. This has profound implications for biology and medicine.

Coherent EMFs may indeed be the organizing agent of cellular processes, which would indicate that the biophoton source is nonbiochemical.[42] It is of course possible that these ultraweak photon fields are somehow related to biochemical processes, although concensus[42] is that they may be guiding the entire cellular physiology. Biofield interactions could also be responsible for the organization of cellular microtubular networks[43] and biological regulation processes that have been shown to occur via endogenous EMFs within microtubular cytoskeleton such as the following: the regulation of the dynamics of mitosis and meiosis[44,45]; chromosome packing during the mitotic phase of the cell-cycle[44]; and interactions between ion channel activity and the phosphorylation status of binding molecules such as MAP2 and CaMKII, which act modulate cytoskeletal structure and connectivity.[46] These experimental data are supported by theoretical prediction of classical and quantum information processing in microtubules.[47,48] The coherent photon field, on the other hand, could be the dominant factor in cellular physiology,[49] a conclusion supported by experimental observations of cell-to-cell signaling via coherent biophoton activity.[36-39]

It is of course important to also consider that neither biophotons nor biomolecular physiology are primarily causative but are instead tightly coupled processes arising codependently within biological systems.

In this vein, it should be recognized that individual cellular or multicellular organisms, while temporally and spatially separate from each other when regarded from customary investigative points of view, actually have no strict and definable boundaries between themselves.[50] In complex ways, living organisms form colonies and populations, merge with influences from the environment as they eat and breathe, behave according to shared genetic inheritance, and are inhabited by innumerable microorganisms known collectively as the microbiome, which makes even a marked visual boundary like the skin quite tenuous. It is just as important to consider the entire biosphere as a single evolving living structure comprising all seemingly separate "beings."[50]

BEYOND BIOELECTROMAGNETICS

Moving beyond classical EMF descriptions, the general CAM approach aims to modulate the endogenous fields. It has been suggested that this aim must include modulation of nonclassical and quantum forms of energy.[25] Indeed, it is a logical necessity to consider that the collective biofield consists of (at least) electromagnetic, optical, acoustic, and nonclassical energy fields associated with biological entities: cells, bodies, perhaps ecosystems, and even Gaia as a whole.[25] As stated above, the coherence of endogenous EMFs suggest, specifically that nonclassical fields are existing in biological entities.[40,41] It has been proposed that the biofield may be applicable in complementary medical therapies and healing.[51]

Potentially such therapies could be directed noninvasively at enhancing or stimulating the body's healing process, reducing pain and anxiety, and a variety of other conditions. Many of these applications reflect the influence of mind/body interactions, suggesting that the role of the observer in quantum mechanics (QM) may be of central importance to understanding mind/body therapies and the role of mind and emotions in health and wellbeing. To what extent "mind" may also be related to the biofield lies outside the scope of this review, but we have been describing some of the basic physical biofield processes that could explain the efficacy of complementary medical therapies.

All physics, including electromagnetic theory, rests upon a nonclassical foundation. For example, the electromagnetic potential field (comprising the vector potential, A, and scalar potential, ϕ, which are the sources of EMFs) mediates the classical EMFs described by Maxwell's equations and quantum levels described by the Schrödinger equation.[22] The electromagnetic potential acts by modulating the phase of charged particle wave functions; field interactions can occur in regions of zero electric and magnetic fields, yet nonzero A and ϕ.[21] Thus the electromagnetic potential is itself a nonclassical field functioning through a modulation of quantum phase rather than via a classical field of force. The case for other nonclassical fields has been summarized by Rein,[25] and such fields, while not yet directly observed, are a direct consequence of both classical, relativistic, and quantum theories.

For example, because the wave equations derived from Maxwell's equations (ie, classical electromagnetic theory) are symmetric in time, solutions exist for both the "advanced" and "retarded" electromagnetic potentials, propagating backwards and forwards in time, respectively.[52] Other field quantities that propagate at faster-than-light speeds, such as pilot waves, follow directly from calculations in both classical and relativistic electrodynamics.[53] In relativistic quantum theory, solutions to the Dirac equation successfully predicted the (now experimentally confirmed) existence of the positron, requiring a formulation in which the arrow of time is reversed.[54] "Longitudinal" or "scalar" waves have also been suggested to be primary aspects of the biofield.[24] In contrast to the transverse vector waves of classical EMF theory, such scalar waves are hypothesized to result from superposition of electromagnetic waves—eg, when 2 waves cancel each other, a transformation of energy into vacuum potentiality is thought to occur.[25] Such scalar fields, which are not mediated by electric dipoles or electron transitions, propagate far from equilibrium[25] and clearly don't constitute known electromagnetic-based structures.

These connections with nonclassical fields have led several scientists to consider the body as functioning as a macroscopic quantum system.[9,25,55-58] The existence of macroscopic biological processes linked to QM leads to quantum biology and as we will see below, to a biofield conception beyond both quanta and biological entities to the underlying vacuum and even further. In an integrated quantum description of the body, bioinformation must play a fundamental role. The implications for biomedicine are profound. Such a system would create a model for the origin and cause of broad physiological regulatory behavior that we currently lack, primary to molecular biology. Practical control of this system would lead to deep insights for healing, regeneration, morphology, disease elimination, growth, and mind/body interaction, as well as insights into the fundamental questions of what is life, what is consciousness, and what the full mechanisms underlying evolution are. It may describe a new, unique, quantum mechanical and electrically based physiological system that interfaces with both the quantum world, quantum vacuum, and biochemical world. It may be the key to integrating the science of consciousness and biology. It would certainly be an epochal paradigm shift for science.

QUANTUM PHYSICS AND QUANTUM BIOLOGY

Quantum physics provides a theoretical entry to attempt to explain the existence of the biofield and how it interacts with the body. There are qualifications to this assumption, however. Bischof indicates the fundamental sense that quantum physics has implicitly replaced the old reductionist and molecular view of science with a holistic one in which materiality forms an unbroken

whole.[23] Likewise, the most persistent paradigm in neuroscience considers the mind as an emergent property of a large and complex physical brain that mediates awareness and remembrance.[58,59] In this orthodox view, "mind" appeared in the evolutionary chain because of the development of nervous systems in general, central nervous systems in particular, or only in primates and perhaps just *homo sapiens*.[60]

In contrast, a view closely linked to the role of observation in quantum measurements assigns a role to subjectivity in keeping with the Copenhagen Interpretation (CI) and particularly its revision by John von Neumann, known as the orthodox quantum view.[6] It holds that consciousness provides the individual observer with agency and freedom.[61-63] As such, quantum measurement theory has yielded to what Wheeler refers to as the "participatory universe." The conundrum of whether or not the falling tree would make a noise in the forest is irrelevant if no conscious observers were around to hear it. From this participatory viewpoint, properties of quanta and quantum systems in general are "contextual": They don't exist by themselves but are intrinsically tied to acts of observation.

In von Neumann's view, nature exhibits free choice of response to an act of observation by an observer. The time evolution of a quantum system is described by the wave function, which fully characterizes such systems through the deterministically evolving Schrödinger equation.[6] However, what value will result following an actual experimental choice is not known. Once an experiment is conducted, a single value in the probability space described by the wave function results, and this is the famous "collapse of the wave function."[64] Quantum theory presents us with a world following a completely different order from the world of everyday experience.[63] In what constitutes the underlying reality, quanta are entangled in both space and time, and nonlocality is implied in quantum measurements.[64]

By extension, a number of quantum physicists take participation to be an absolute requirement, holding that the world is primarily mental, since mental decisions implicitly play the primary role in the collapse of the wave function.[6,57,64-66] In the CI of quantum theory, the wave function is not considered to be real. Rather, it is only a prescription of determining probabilistic potential outcomes, which are described by the square of the absolute value of the wave function, as proposed by Born.[67,68] However, the variables measured must conform to macroscale classical analogues, since any apparatus in the lab would be a classical system. Thus the CI has a duality built into it. Not all physical variables of a quantum system can be simultaneously known (according to the Heisenberg Uncertainty Principle). In the CI, quantum systems behave in a complementary manner, either as particles or waves (Bohr's Principle of Complementarity). This complementary relationship manifests in the act of observation itself. For example, the more precisely a particle's position (particle-like aspect) is measured, the less precisely can its momentum be known (ie, wavelength or wave-like aspect). Thus the type of measurement chosen by the observer determines the outcome of experiments, suggesting a participatory role for the observer.

In von Neumann's view, there is a universal wave function.[6] However, as in the CI, there is also collapse through conscious observation. For von Neumann, the state transformation due to measurement (process 1) is distinct from that due to time evolution (process 2) as described by the Schrödinger time-dependent equation: Time evolution is deterministic and unitary whereas measurement is nondeterministic and nonunitary.[6,58] Von Neumann's interpretation is the gold standard against which all other interpretations must be compared.[63] Von Neumann's nondeterministic interpretation of measurement gives a psychological component to reality itself, casting the observer in the role of an active participant in the creation of events.

This viewpoint, that the observer's participation plays an essential role in the outcome of events, has fundamental implications for biofield science and mind/body therapies. It has the potential for understanding how many such therapies operate. In the same breath, the issue of efficacy arises. There is a wide range of response to all medical interventions, whether in complementary or conventional scientific medicine. No 2 patients respond alike, and uncertainty is always present. Mind and body are fundamentally connected. Thus, the primary connection of the observer and the observed system, as understood in QM, has profound implications for the nature of the biofield: We cannot take the living body as an entity existing independent of the biofield to which it belongs and independent of the practitioner and the receiving subject in CAM treatments.

The primary shortcoming of molecular biology is that the "holistic" character of the physical world now recognized in quantum theory is either not acknowledged by the bioengineers or rejected as irrelevant.[23,69] The world view of QM is much richer and more holistic than molecular biology would have. It is no surprise that many of the founders of QM understood the implications of wholeness in both physics and biology. For example, Planck held that wholeness must be introduced into physics as in biology.[70] Bohr understood the significance of complementarity beyond QM and how it was paramount to biology.[67,68] Schrödinger wrote an important work with the title "What is Life?" in which he approached the holistic view for both QM and life as similar.[71] For example, primary colors are not a fundamental property of light but are related to the physiological response of the eye to light. Moreover, Heisenberg also held that mind plays a fundamental role in the universe.[72]

Today, the evidence of macroscopic quantum effects in biology has yielded a plethora of phenomena that can be understood through the application of quantum physics. They include understandings of the role of

coherence in photosynthesis,[73,74] the avian compass through which birds navigate,[74] the sense of smell,[75] quantum coherence in microtubules,[56,76] regeneration,[77] and quantum processes in brain dynamics.[78-80]

QUANTUM-LIKE PROCESSES

The application of quantum microphysics to macroscopic scales is natural and yet at the same time surprising. The naturalness is because QM is the most complete theory of physical reality that we have where classical physics is incomplete. The surprise is because most QM effects occurring in the microcosm, such as entanglement and nonlocality, don't readily apply to everyday experience. In what follows, we refer to Kafatos[63] as it applies to bridging the microscopic and macroscopic domains.

By quantum-like effects are meant (1) phenomena that are clearly related to QM but apply at macroscopic scales where normally they would not be expected and (2) phenomena that should be seen as extensions beyond current orthodox QM, in particular those involving life processes that cannot be accounted for by standard biochemistry, biology, or quantum theory. The Hilbert space formalism of QM, Schrödinger's wave mechanics, and Heisenberg's matrix mechanics don't directly address life processes. Quantum-like processes have been theoretically invoked in a host of life processes and macroscopic physics (such as brain dynamics).[7,8] "Quantum-like" indicates that the principles of QM apply at all scales, not just the microscopic, and as such, they provide fundamental insights to phenomena in fields outside physics, such as those already touched upon—biology, neuroscience, and medicine—and potentially extending to other areas like psychology and even anomalous psi phenomena, where one might apply QM phenomena such as entanglement and nonlocality.[81]

Reflecting on these concepts from the perspective of complexity theory, it becomes clear that many of the "peculiar" effects observed at the quantum level have biological forms: for example, biological complementarity[50] and uncertainty.[82,83] Extending QM concepts in this way leads to biological scale, quantum-like nonlocality, recursion, and entanglement. These extensions are more than analogies or metaphors. Beyond a scope usually considered as peculiar to the quantum world and not occurring in the "real world" of classical physics, we suggest that if the observable universe at its foundation is quantum mechanical, as held in standard orthodox QM,[6,58,84,85] then nonlocality could indeed be one of the signature aspects of an underlying mental world. This has been referred to as the "conscious universe."[64,85-88] Such a universe, where consciousness is primary, would entail *qualia* of experience, where the qualities of the experienced world describe reality with the validity of conventional science and yet go much further by including every aspect of mind.[89,90] Quantum-like can thus be understood as the (future) extension of both QM and quantum biology[91] to account for the physical, mental, and biological realms,[92] with the biological domain characterized by huge complexity and different levels of information rates.[1]

THE QUANTUM VACUUM

In interpersonal field phenomena,[23] the presence of nonelectromagnetic fields is indicated. These may be electromagnetic potential fields, which Aharonov and Bohm[21] showed are very real. Tiller has suggested that these potential fields mediate between EMFs, the macroscopic quantum states of matter, and the physical vacuum.[22] We agree with Bischof that "all the features of unbroken wholeness of reality implicit in quantum theory—non-separability, non-locality, fundamental connectedness—which are so fundamental for biological understanding, are an expression of the properties of the vacuum."[23] According to this view, the vacuum organizes the structure of space-time through macroscopic EMFs, and the phase-controlling property of the electromagnetic potentials plays a central role.[23] The importance of phase-relations for complex biosystems, consisting of many oscillating fields coupled nonlinearly by their phase-relations, points to the importance of the vacuum for the biofield itself.

Relatedly, the coherence of biophoton emission has been suggested to arise from "potential information" in the organism that is virtual and nonmeasurable[23] and a "superfluid vacuum model" has been proposed for biophoton emission of seeds and its connection to their vitality.[93] This model characterizes the vacuum as a superfluid Bose-condensate of photons in which virtual fields in the vacuum state are involved in the manner posited by Grandpierre and Kafatos.[94] Zeiger and Bischof make clear "that there is significantly more to the quantum vacuum than just the electromagnetic vacuum (the zero-point fluctuations)," and

> *the need for assuming a pre-physical dimension of potentiality for the understanding of organisms, and for the creation of the new discipline of vacuum biophysics as a basis of biophysical understanding, is postulated . . . The fundamental quantum mechanical nature of biological phenomena will only be fully understood if the vacuum is taken into full and explicit consideration as the essence and ground of these phenomena. The quantum vacuum may serve as a framework for a unification program in biology aimed at incorporating all relevant aspects of life into a physical picture of the organism.*[93]

In agreement with views presented above, Zeiger and Bischof also recognize the role of the observer and of consciousness itself in QM.[92] In addition, Grandpierre and Kafatos and Grandpierre, Chopra, and Kafatos have provided arguments for the fundamental role of the quantum vacuum in biology, in the autonomy or free choice of organisms and as the driver of biological evolution.[94]

PRELIMINARY RESULTS FOR "PHANTOM LEAF EFFECT": A MODEL SYSTEM FOR BIOFIELD RESEARCH?

An intriguing experimental result, known as "the phantom leaf effect," if fully verified, may be an example of some or even all of these biofield processes. In these experiments, coronal discharge[95] or the Kirlian photographic effect reveals a field effect in the morphological form of an intact living leaf even after part of the leaf is severed.[96] This suggests an analogy to the subjective experience of a phantom limb reported by patients after the limb has been amputated. There might be a persisting biofield that represents the amputated limb. First described by Adamenko and reported by Tiller[96] and by Ostrander and Schroeder,[97] more recent validating experiments have been performed with detection methods of greater precision; these are summarized in Hubacher.[98] In his most recent publication, Hubacher performed the experiment with highest definition photographic samples using the largest number of samples to date.[98] Of 137 leaves severed and imaged, 96 (70%) demonstrated clear phantoms (example in the Figure).[98]

In these experiments the phantom structure (1) appears as an integral and coherent whole, (2) is independent spatially of the organism, (3) interacts with both magnetic and electric fields and conducts current, and (4) represents the precise anatomy of the original physical leaf.[98] Hubacher concludes that the phantom leaf, being electroconductive, may carry both information and energy and therefore possibly represents a true biofield manifestation that regulates physiological processes.

An early explanation of this effect questioned whether the phantom leaf effect might result from moisture emission from the cut portion driven into the space from which the cut section had been removed by the power of the field emission process. However, the most recent data do not support this explanation, as the precise and complex anatomical replication of the original leaf is present in minute detail.

On the other hand, it is also unclear why the effect is not seen 100% of the time (though it is more reproducible in this current cohort than it has been before). Hubacher suggests that

> *some parameter or group of parameters is probably needed beyond what is understood, to reliably reproduce these results. These include such things as frequency, waveform, dielectric spacing, pulse widths, and types of grounding. Other variables can include film types, gases in the electrode mechanism, humidity, power sources, times of year, plant species, [and] chemically influenced specimens, eg, perfusion with chloroform prior to photography.*[98]

Further work is clearly needed to determine the impact of these variables, but the fact remains that phantom leaves have been demonstrated using a variety of techniques. The remarkable results strongly suggest a robust effect that can arise from a very broad array of interwoven field phenomena.

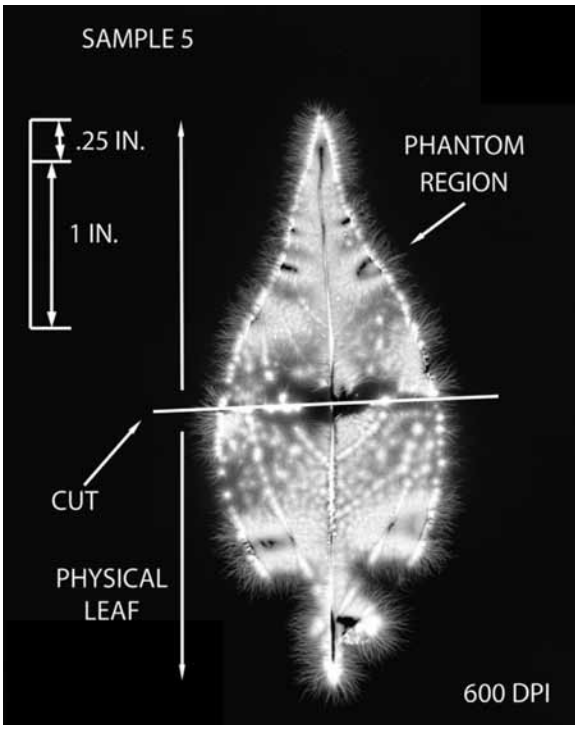

Figure Example of the phantom leaf effect from Hubacher (2015).

In the images obtained, it is electron flux that creates the image. These data point to the existence of an intact, integral, and conductive system permeating the original leaf. Given the absence of any conductive physical structures in the severed area, the coronal discharge appears to be under the influence of a quantum-level, nonphysical field functioning below the level of EMFs, in order to support and structure those EMFs. Vacuum phantom effects have also been proposed at the molecular level for DNA.[99,100] We note also that the quantum vacuum produces real measurable effects such as the Lamb shift,[100] the Casimir effect (which occurs when charged parallel electrodes are closely adjacent[101]), and the Bose condensation mentioned above.[30]

The mechanisms are as yet unknown, but the various findings point to aspects that would be expected from the postulated biofield. It can be asked, then, whether a phantom structure functions like a true physiological system, as has been suggested for the biofield. A functioning system of this nature has been postulated to deliver energy and/or information systemically throughout an organism using electromagnetic signals and forces.[9]

In this regard, it appears that the phantom leaf effect may provide an excellent model through which to explore the manifestations of a truly observable biofield (or of overlapping, interactive biofields). At the very least, the opportunity to explore biofield mechanisms at the level of EMF or below, into subtler quantum realms, is intriguing. The fact that the phantom leaf effect is highly robust in recent trials[97] suggests that further

work will identify confounding variables, which will likely uncover some of the underlying principles.

DISCUSSION AND CONCLUSIONS

Our examination of the evidence for the biofield indicates the need for explanations to go beyond conventional classical physics and biology. In particular, one needs the consideration of holistic approaches and coherent processes. Biofields may be carried by EMFs, quantum and quantum-like processes, and other fundamental coherent states. Further research must be done on the physical origins of the biofield and how it relates to an integrated understanding of consciousness and the "living universe." Our recommendations include new investigations that address the comprehensive issues listed below, some of which are currently speculative.

- What is the role of observation in the structure of the biofield? Does the state of the practitioner affect the structure of the biofield in medical applications, for example? Even for the same subject receiving different CAMs at different times, would the biofield depend on the person administering the treatment?
- Is the coherence seen in biofield, and particularly in biophoton emissions, indicative of the basic quantum(like) nature of life? Similarly, do nonlocality and entanglement and other quantum properties apply among different interacting organisms?
- In CAM, how is the endogenous and all-encompassing nature of the biofield in an individual tied to the biofield of the practitioner and to all biofields of living entities? For example, do biofields linking every living entity exist at all scales? How would we show this experimentally and what would the consequences be?
- If entanglements across "different" biofields are real, how might CAM modalities be developed to deliver the maximum beneficial effects to the patient?
- Can the use of CAM take advantage of the nonlocal nature of the biofield (eg, along with hands-on healing, distant healing, as in Reiki, could be equally effective)?
- Can the biofield be understood as ultimately emanating from the quantum vacuum? Would this open up new vistas for energetic healing transmission? For example, would the persistence of biofield be utilized for health benefits across space-time?
- Can we devise scientific experiments to study specific quantum-like properties of the biofield that would be useful in CAM?
- The phantom leaf effect may represent an easily performed and reproducible model system for exploring not only the primary nature of the biofield but also how CAM interventions might interact with it or even change it.
- Finally, what makes biofield research so fascinating is its immediate impact on human beings. We are living entities imbedded in the fields described by classical and quantum physics. Nature's forces invisibly affect us every day, and science has long searched for a bridge between the quantum and classical world. If these worlds turn out to be united in a very practical way through the phenomenon of life itself, the biofield will be far more than theoretical. It will redefine what human life constitutes, where we belong in the panoply of life on the planet, and ultimately how we should live in a wider, even cosmic, context.

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