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Quantum Biophysics: Exploring the Role of Quantum Mechanics in Biological Processes

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Annotation: The role of quantum mechanics in biological processes is examined. Experimental results show that quantum superposition and entanglement are functioning also in biological systems. A spectrum of emerging quantum biophysics reveals the reasons why they have been overlooked for such a long time since nature seems to be prepared for a seamless unification of the described world. What explains these formal findings, and what can come averagely out of this knowledge for biology and biotechnology? Biological systems, 'machines', and processes work undeniably best under ambient conditions. As a result, there is a well-established stance treated throughout the history of modern Science, and of physics in particular, to consider non-classical solutions and quantum effects significant only from inertial scales. But can these general statements be confirmed analytically for magnitude as large as cells, DNA chains, or even on low-density laser-cooled atoms or molecules? From investigating laser light plus cold atom-molecule experiments, living systems, and especially biological organisms might emerge as truly astounding quantum machines. This comprises already established quantum biophysics near fields and lasers at sub-bio scales along with manipulations of single molecules. Relying on the rudiments of quantum theory developed a century ago, quantum mechanics has successfully reconstructed a sequence of experiments and opened up dimensions far beyond a spiration. There exists a virtual unbounded domain of far less recognized yet increasingly powerful quantum formalism where quantum biophysics may straddle an entirely novel frontier between physics and life sciences. The present study makes an effort to fleet some light at the frontiers of quantum/classical on non-inertial laboratory-biological bridges on the way towards a rigorous unification of quantum mechanics and bio processes. For this purpose, the interplay of recent investigations in atom optics and tissue optics is scrutinized. A brief resume of experiments on laser irradiated DNA plasmids testifies the aggregate complexity, optimalization, flexibility, and well reserve of charge/storage capacity of double-helix symmetry. On the other hand, there has been a slump of woodworking results proving the contested stability of even larger unrelated biomolecules. Conjecture the operative structural styles through steady-state refracted coherence trapping, biostatistical populations and cellular/experimental targets are largely partitioned.

1. Introduction to Quantum Biophysics

Quantum biophysics is a field of science that aims at understanding the life sciences with quantum mechanical methodology. This is an interdisciplinary area where quantum mechanics together with biology are used to explain biological phenomena. The field comprises a diversity of scales from the subatomic, organic, molecular, and cellular levels to tissues and whole organisms. Several significant advances were made in the last few years that conciliate biological scales with quantum mechanics as well as challenge quantum mechanics at macroscopic scales. Furthermore, scientists posed the question of the role of quantum mechanics in life. In light of the recent advances, ongoing debate, and the century-long inertial view, it is still unclear and a ripe topic to explore the role of quantum mechanics in biological processes [1]. Some biological phenomena probe a coherent quantum superposition of states that quickly decoheres. Understanding the role of quantum mechanics in these biomolecular processes may lead to novel quantum mechanical methodologies and biological applications. As an interdisciplinary area, quantum biophysics demands a solid grasp on quantum mechanics and biology. Quantum mechanics studies light and matter interaction. In 1905, Planck proposed the existence of the quantum of action, coupling the Planck constant to the black body radiation. He won the Nobel Prize in 1918. Quantum mechanics is increasingly viewed at scales broader than atoms, molecules, and solid states, abstracting black-box effective theories. The Schrodinger-Newton equation is such a more complex quantum theory of phenomenological macroscopic gravity intended to be compatible with both non-relativistic quantum mechanics and Newtonian classical gravity. Such efforts probe a reconciliation of quantum and gravity in bio-compatible scales. On the experimental side, superconducting quantum interference devices (SQUIDs) have a renewed interest that may be used to probe quantum mechanical properties of biological systems, such as magneto encephalography for brain research and magneto cardiographs for heart studies. It was proven in the experiment that the protein bovine rhodopsin with retinal claims the quantum resonance electron tunneling by using the SQUID technique [2].

2. Fundamentals of Quantum Mechanics

Quantum physics was first built to make sense of microscopic phenomena with photons, electrons and atoms. Most probably, it is rooted in the insight that the state of an isolated particle is described by complex probability amplitudes rather than by real properties. Four equations shape the dynamics of quantum particles and fields: the Schroedinger equation, the Heisenberg equation, the Klein-Gordon or Dirac equations for particles with spin, and the quantized Feynman rules for field amplitudes. The rules designate interaction, superposition, entanglement and the collapse postulate [1]. More than with any other fundamental theory of nature, quantum physics is conceptually challenging and remains disputed up to today. Hence, the natural question is: What is the role of quantum physics in and for biology? Since 50 years, this question arises most naturally in the context of molecular structure and bio-chemical ionisation, yet notions of chemically assisted energy transfer were proposed even earlier. It is an utmost challenge to give a comprehensive answer to such a broad question which, depending on the perspective and interests, may range, a priori, from quantum physics in simple chemical and physical processes of biomolecules, over quantum metrology and hybrid systems or life sciences using quantum-information-theoretical methods to concepts of closed-time-path quantum field theory in complex, many-body settings. Rather than providing a thorough analysis of one or a few such subfields, an overview will be conveyed with a rather broad definition of what denotes the interface between quantum physics and biology. The alterations of the conventional quantum measurement theory required in order to account for the state vector reduction after measuring an old quantum suggest that more sophisticated models of the measurement process could, in principle, account for the apparent effect of consciousness on the reduction of the quantum state. This provides, in principle, a global interaction with the quantum wave function. The nonlinear character of the proposed modifications of quantum mechanics may be implemented by real physical processes and have testable consequences. This approach can also model a possible correspondence between brain and consciousness. The emergence of a self-induced reduction seems a good candidate for the mechanism underlying the hypothetical divergence of quantum mechanics from a fundamental deterministic theory. At the present stage the implications of quantum measurement theory on the psyche-brain interaction can only be considered as a general working hypothesis. Given in statistics such a large variety of possible correlations and the unpredictable evolution of the environment, instances where extraordinarily strong correlations occur by mere chance are likely to be entirely missed, and are irrelevant. Therefore, better rates will eventually be achieved if the frequency of the outputs is determined, an analysis of the entire daily or weekly record is undertaken, and the endpoint of the experimental series is awaited. With specific regard to parapsychological research, and in view of the enormous difficulties connected with such experiments, it is suggested that this would be the only way to obtain more reliable and definitive results, and that the present lack of repeated experimental series might also be the reason for the present scarcity of positive findings. [3][4][5]

3. Historical Context of Quantum Biology

In forces or sensing one is likely going to discuss electronical excitations which are quantized because the atoms they jump between are discrete and well described by quantum mechanics. While biology is all about hydrocarbons that on the one hand look like beautifully unproblematic fields due to the enormous number of degrees of freedom. Here using modern eyes and understanding much of biology's depth is called upon in real shocks and quantum effects may be only coming light with the benefit of using quantum mechanics [1].

Quantum biology is an emerging field that addresses on the one hand qualitatively new mechanisms, and on the other hand the use of known quantum systems in completely novel settings. Also interesting is the implications of being a solid observer in many-body quantum system. A clear theoretical investigation will be made on the controlled generation of entangled two-body discrete quantum time crystals between two ultracold atoms. A quantum measurement backaction allows the adiabatic manipulation of the energy crystals and may find application in precision sensing within nanomagnetometry, electrometry or gravimetry. A distinctive feature of the resulting excitation landscape is having a fractal Weyl spectrum with hidden chiral degrees of freedom at each band-touching point. When a Uniform magnetic flux is threaded along the network ringlets, other sort of quanta are built in a “manifold” manner – chiral bosons whose localization is intimately tied to the presence of the Weyl time reversal invariance ensuring them to be fully robust against local perturbations [2].

Quantum physics is helpful to understand biological processes as the functioning of many systems can only be explained by addressing quantum coherence effects. One of the biggest origins of skepticism about claims that quantum processes play a significant role in biology is the high temperature of all biological organisms. It is clear that biology exploits the quantum mechanical nature of reality. However, as experimental techniques improve, investigators are identifying subtle signatures of quantum behaviour in an increasing number of biological processes. Clearly, the field of quantum biology is at an early stage, analogous perhaps to that of protein crystallography more than a century ago. Given the implications of these discoveries for many aspects of biology and medicine, the study of the role of quantum mechanics in biology is a field with a bright future.

4. Key Concepts in Quantum Biophysics

Modern biology, pharmacology and medicine are still deeply rooted in a growing understanding of molecular interactions and, in turn, in the mature awareness of a subtle art to interfere and control such processes chemically or, more directly, physically. In contrast to its historic origins in the philosophical attempts to understand the macroscopic world, quantum physics has been mainly centred on microscopic phenomena, quantum of action and quantum of energy being the originally detected ‘quantum manifestations’. Though the size scales of both, the natural domains of physics on the one hand, the life sciences on the other, have steadily approached each other, the role of quantum physics in the latter might be regarded as a curiosity, since biology is very large and quantum physics is very small. Indeed this statement not only expresses the obvious general sense why classically educated minds might keep sticking to classical intuitions in knowledge reconstruction, but also implies an encouraging simplicity: biology represents an object supposed to be amenable to rifutory, but deterministic considerations by performing partial differentiation with respect to an envisaged biosymmetric setup of variables and parameters, a formalism exploiting quantum superpositions and cluster properties of matterwaves. Modern biology and subcellular experimental biophysics in contrast have shown that the hydrodynamics-like behavior of what one might have crudely coined magnum corpuscles does not straightforwardly carry over to constituents of sizes matching the de Broglie wave length. Trying to mathematically describe bio-particles always heading towards sizing up the relevant observables subclasses – position and momentum in the classical treatise – poses obvious problems. Enter ultra-diffusion. In addition to giving rise to qualitatively new, classically hard to approach biological phenomena that said classically driven minds may regard as chaotic and nonsensical, it seems, ironically enough, as the valid physical paradigm for living matters of the real world. Hyperdiffusion will be shown to originate as a natural and physically accurate description of those fluctuations seemingly defying the classical diffusion laws. This dynamics will manifest its profound impact on the characterization of microscopic non-ergodic species, experimentally posing intractable problems within standard classical analysis. Finally, hyperdiffusion will motivate some thoughts on its potential exploitation for imaging information locked in the microstructure of intricate systems. [6][7][8]

4.1. Quantum Superposition

Quantum science is mostly formulated and applied to microscopic objects, whereas biophysics usually deals with questions in the realm of our sensory experience—objects at the micro and macro scales. Everyday life requires rationalizing—through a purely classical understanding—how states of a large ensemble of interacting systems evolve. Success in this pursuit has so profoundly influenced humankind throughout the last four centuries that quantum science stands out as a major achievement of human intellectual effort. However, a particular ground-state wave-function describing a quark confinement region was in a superposition of two colour states. This suggested quantum methodology could be more related to the properties of biological matter than had been previously believed. Roughly speaking, the quantum description of an isolated physical system is formulated in terms of Hilbert-space vectors, which are elements of a separable Hilbert space. There can be some issues with a quantum mechanical description of some biophysical systems, particularly those inside a biological entity being not fully self-contained. When closed systems interact with the external world, they form an open one. Canonical quantization is based on promoting classical Poisson brackets to quantum commutators. For some biophysical systems, the canonical quantization scheme should be reformulated with more general choice of commutators, the operator being then Hermitian with respect to new scalar-product. Evolution of this density operator is generated by a master equation. Probability distribution of positions of macroscopic objects satisfies the standard diffusion equation. However, in microscopic interpretation, quantum mechanics makes a different prediction; wave functions of the microparticle alone will never lead to the object's dynamics that can be interpreted in a classical manner. The attribution of definite states can be essential in maintaining classical-like dynamics [1]. For this to happen in a quantum system interacting with its environment, a process called decoherence is currently assumed to take place.

4.2. Quantum Entanglement

Since a main part of the claim of quantum biology is made for quantum entanglement processes in life science [1], and a vast recondite many of the claims of quantum biology are decidedly more extravagant, it seems factual to focus here on quantum entanglement. Why's this rather than godzilla reproduction or broccoli biosecrets? Besides the above quantifiable imbalance, there is some preliminary work on quantum entanglement in biological contexts (though quite a lot of it is really pretty dire).

Entanglement would seem to be an exultantly apposite property for modeling a suite of physical-chemical processes preceding life, the most recognizable of these being as a foundation stone of the EPR paradox and Bell's theorem. The claim for such processes occurring in life science generally posits that entanglement of at least one duple degree of freedom of a bipartite quantum system in matrix of entangled states. Biological systems involved in these processes are thus said to exhibit nonseparable superposition states otherwise known as entangled states. Advice to better half: Stress calcium and magnesium intake. It's didn't understand a word of it either, honey, but apparently your DNA, or it could be your fulvic acid, has become one half of an entangled wave function that's fallen into a non-local topological shape of a Moebius strip.

4.3. Quantum Tunneling

Quantum tunneling was described by [9]. It was discovered in the late 1920s to explain radioactive decay and field electron emission in vacuum tubes. Today this phenomenon is at the core of many essential technological innovations such as the tunnel field-effect transistor, field emission displays and the scanning tunneling microscope. Tunneling also plays a key role in energy and charge transport in biological and chemical processes. The modeling of deactivation processes of a kinase channel is presented to explore the role of quantum tunneling in biological processes. Collective tunneling is investigated in a disordered system of flux qubits. As compared to an isolated qubit, interactions with a few neighbors can drastically change tunneling characteristics and resulting relaxation rates. Analysis of tunneling at multiple tunnel barriers in a quantum annealer is also presented. This part illustrates the fundamental difference between classical and quantum tunneling and its importance for optimization. reconciling paradigm is that at least some bio-molecular mechanisms are based on the principles of quantum biology such as negative absorption, quantum coherence and quantum tunneling. In fact, tunneling effects have been theoretically observed in a DNA model and quantum transport of electrons in DNA has been experimentally observed. It motivates the search for a destructive natural selection of isotope atoms and catalytic processes. The restless Earth model based on stochastic jumps in ions and solitons due to tunneling is also investigated.

5. Quantum Effects in Photosynthesis

During the first steps of the process of photosynthesis, the light-harvesting biomolecular complexes transform the energy of solar photons into electronic excitation energy. On a relatively short time scale, the electronic excitation energy is subsequently channelled to the reaction center where the solar energy is stored in the form of a chemical potential that is then used to drive the chemistry of life. The energy transfer from the light-harvesting complexes to the reaction center proceeds via exciton quasiparticles, i.e. resonantly excited delocalized quantum superpositions of electronic excitations that move between individual pigment molecules on timescales of the order of several tens to hundreds of femtoseconds.

There is a long-lasting, heated debate in the field of biophysics whether the energy transfer dynamics in the initial, fast energy funneling steps of photosynthesis is smooth and fully described by the phenomenological observables of the quantum master equation approach or there is a subtle quantum waltz that the native cellular biomolecular complex executes beyond the reach of current experimental techniques. The theoretical prediction of remarkably long optical coherence times in photosynthetic pigment-protein complexes raised huge expectations as well as doubts. On the one hand, the observed build-up time of excitonic coherence that is reminiscent of a typical quantum beat oscillation in condensed-phase systems would suggest the solid-state photosynthetic pigment-protein complexes are perfect quantum devices. Such coherent oscillations would be undamped in a perfectly pure system and survive as long as the phase memory time of the quantum wavepacket, i.e. the lifetime of the state, is still available. On the other hand, the spin-boson model and subsequent theoretical and experimental work demonstrated that quantum coherence in the FMO complex is short-lived sub-100 fs. A time-dependent broadening of the inhomogeneous distribution of pigment sites and/or an electronic energy gap make the coherence generated by the chromophore unobservable within 200-300 fs after the initial excitation and a recombination. No quantum beating of the electronic coherences is observed by the anisotropy or by partitioning of the spectra within the detection limitations of the setup. A theory on the time-scale of the electronic energy transfer compared to the onset of long-lived quantum coherence suggested that relevant quantum information should be encoded. Contrary to the above theory, the prominent 60 fs peak in the FMO spectra is not a signature of long-lived electronic coherence. The calculations on the FMO and the LH2 complexes suggest that an initially delocalized superposition of electronic excitations decoheres within 20 - 40 fs, long before the onset of energy transfer. [10][11][12]

5.1. Light Harvesting Complexes

During the first steps of photosynthesis, the energy of impinging solar photons is transformed into electronic excitation energy of the light-harvesting biomolecular complexes. The subsequent energy transfer to the reaction center is understood in terms of exciton quasiparticles which move on a grid of biomolecular sites on typical time scales less than 100 femtoseconds (fs). This energy transfer is described as an incoherent Förster hopping with classical site occupation probabilities, but with quantum mechanically determined rate constants. Here, we demonstrate that the optical 2D photon echo spectra of this complex at ambient temperature in aqueous solution do not provide evidence of any long-lived electronic quantum coherence, but confirm the orthodox view of rapidly decaying electronic quantum coherence on a time scale of 60 fs

[13]. These results give no hint that electronic quantum coherence plays any biofunctional role in real photoactive biomolecular complexes.

It is widely considered that during the warm and wet early Earth, before biological systems developed, fueled by ultraviolet solar light, the photon energy of lyophylised nucleotides on a warm ice surface converted into electrical field excitations along the sugar-phosphate backbone. This process could drive (i) inosine 5'-diphosphate with its nucleobase pointing out of the helix into single nucleotides (output), and (ii) helix-forming nucleoside 5'-monophosphate dimers, and subsequently trimers, on which only one nucleobase or the connecting sugar take part in base pairing into a helix on the ice surface (input). Concerning the non-helix forming dimers and trimers, the nucleobase was shielded from the electrophilic attack of UV and OH radicals provided by the H2O ice. The outcome might be the establishment of a selection principle favoring the right (A:T, G:C) base pairing. Potential latecomer terrestrial water together with ballistic forces of ice grains caused by temperature fluctuations could promote the first base pairing-based self-replicating function, and hence the emergence of the genetic information spirit. [14][15][16]

5.2. Energy Transfer Mechanisms

<p>Quantum biophysics is a new interdisciplinary field of research in which quantum mechanics is applied to biological systems. This work aims to give an overview of historical and recent discoveries in quantum biophysics and to provide an up-to-date guide for prospective students and researchers looking to work in the field. Basic terminology and background information about quantum mechanics that are relevant to biology are given first. Subsequently, topics in quantum biophysics are explored and discussed, emphasizing the three different and distinct strengths of the quantum approach when it is applied to biological problems compared to a classical approach: bioeffective resonances, quantum coherence, and long-range intermolecular forces.</p>

<p>Quantum mechanics is one of the most successful theories in science and in technology. It facilitates the development of a semiconductor-based industry, a new branch in medicine, and another in genetic engineering, and provides new devices for a variety of purposes. Now quantum mechanics is applied to biological systems and new insights come out which have been ignored over the years by biological scientists. Of course, DNA is a quantum system, like any other substance, and its physics needs to follow quantum physics. But transcriptions, replications, and mutations, all related to the propagation of life must show new aspects. A lot of questions are: Does biology need quantumness? What does quantum biology tell us? And, most of all, what aspects of quantum mechanics can help biologists understand these phenomena better?</p>

<p>In the first part of the lecture, a brief overview of some of the current applications of quantum biophysics are explored. Topics range from the spectroscopy of small biological molecules all the way to the development of neuroscience and human-computer interfaces. Pharmacodynamics and the interactions between drugs and receptors are discussed, as is the interplay between quantum pharmacology and pharmacokinetics. Additionally, quantum bioeffects are touched on. These topics all provide a foundation and context for the discussion of bioeffective resonance in the subsequent sections of this work.</p> [17][18][19]

6. Role of Quantum Mechanics in Enzyme Function

The background consists of two parts. The first part relates to a suggestion of implementation of a toy quantum channel description of the mechanism of enzyme action and the subsequent recent investigations of possible evidence for quantum mechanical operation of ion channels in biology. The second part consists of an overview of present knowledge of enzymes and a suggestion that the potential lack of action of strong enzymes in a genuinely quantum mechanical context is misleading.

In the early stages of examination of quantum mechanics, considerable efforts have been made to look for potential experimental refutation of quantum mechanics. This continues up to the present time with recent suggestions that macroscopic quantum superpositions could be both prepared and observed. There has also been attention to possible natural quantum systems which might manifest the non-trivial impacts of quantum mechanics. Attention has lately turned to the role played by quantum mechanics in biological processes. It is seriously remarkable that it has not been recognized before that life is an example of collective quantum computation. Both problems are concerned with the transformation of matter. The one to make it inoperative, the other to make it act in ways determined by life. The enzyme catalyzes a chemical reaction by way of a complex multi-step process described by the conformation dynamics of the active site. This may either constructively internalize reaction barriers in an energy sense or play the role of a tiny nanomachine to control the entropy of the barrier region in a way to increase the probability of enabling a thermal jump.

Enzyme action is accompanied by the aforementioned conformation dynamics of the enzyme-substrate complex as it passes through inflexible transition states. It is actually the Brownian motions of the carbon atoms of the complex that directly produce the chemical reaction. A question of interest is which quantum state is best suited to describe the complex. Is it described by a density matrix of Gaussian distributions of statistical populations and corresponding average conformations? Or is it best described by a pure state of the conformations? This paper suggests that the simple-state model is the one that best accords with the known data and hence that there is no strong biological catalysis if the quantum states are actually strong and not a compound Markov process. [20][21][22]

6.1. Quantum Tunneling in Catalysis

Recent developments in the field of Quantum Mechanics and its relationship with biological processes suggest that a new area in biophysics has emerged. The remarkable biocomplexity found in living systems suggests that biological systems can exploit high-level ordered structures and dynamics to perform their biological function with high efficiency, selectivity, and specificity as well as, with very low energy dissipation. How these biological processes evolved is still an open question. Quantum Mechanics is a good candidate to contribute to this issue. In fact, Quantum Mechanics appear as a natural framework to describe processes where extremely high efficiency, selectivity, and specificity are required.

Quantum tunneling plays a critical role in energy and charge transport in biological and chemical processes [9]. There is an extensive theoretical work on describing and predicting tunneling driven rate processes. Moreover, a series of experimental studies have reported evidence for the occurrence of charge and energy tunneling in a broad variety of systems. A fundamental model system for investigating tunneling effects in chemical reactions is barrier tunneled H + H2. Although tunneling prolongs the reaction lifetimes it is not sufficient for the onset of LZB behavior in barrier tunneled chemical reactions [23]. Biochemical processes consists of a series of reaction steps, in which each step involves a very specific molecular interaction, i.e. a lock-and-key mechanism. Nonetheless, catalysis allows a much faster conversion of reactants into final products. Catalysis often involves very specific enzyme-substrate interactions. Approaching the substrate, an enzyme can modify the mutual arrangement of its active site atoms creating a channeling effect for electrons and protons. As a result the reaction kinetics is faster than the reactants under thermal regime, hence tunneling catalysis. With a first numerical study carried out on a realistic model for enzyme-catalyzed reactions, it is explicitly shown that tunneling catalysis is always efficient in term of time and reaction yield also when the entire catalytic cycle is modelled.

6.2. Proton Transfer Mechanisms

Various biological processes involve the conversion of energy into forms that are usable for chemical transformations and are quantum mechanical in nature. Such processes involve light absorption, formation of excited electronic states, excitation energy transfer, electrons and protons tunnelling which occur in photosynthesis, cellular respiration, DNA repair, and possibly the magnetic field sensing. Quantum biology uses the benefits of up-to-date computing power to model complex biological systems, and to interpret some experimentally observed phenomena in the frame of quantum mechanical effects. Proton and electron transfers play a key role in many important processes in biological systems, such as the enzymes break-down of food and obtaining energy in cellular respiration. Herein, four principal protons transfer mechanisms are considered – first, characteristic of biomolecules; second, cell membrane protons pumps; third, reversible tautomerization; and fourth, amino acids composed an environment for the protons transfer by other biomolecules and water-mediated interactions [24]. This greatly progressed framework shows how concerted time-dependent proton and electron transfer pathways are very vital in some biological processes, like enzymatic activity.

Proton transfer processes play an essential role in a wide variety of biological processes, including the energy harvesting in biological systems, proton pumps of the respiratory chains, in the bioluminescence, the DNA replication, and others. Over the 80s, some of the principal theoretical efforts of biology researchers were made to understand multiple subtle aspects of the proton transfer in biology. However, as for the time of calculations, only primitive models and few methods for it are available. That is why research on the development of the qualitative and quantitatively new vision for the protons transfer processes, that nevertheless might include all the previous knowledge as particular cases, persists quite acute initiative today 30 years later. Proton and electron transfer often happen simultaneously in some biological processes. They occur on comparable time and space scales then can not be treated independently and in this case, proton and electron transfer paths are carefully correlated.

7. Quantum Biology and Sensory Perception

Quantum biology is an emerging discipline which applies quantum mechanics to model biological processes and explain non-trivial phenomena observed in living beings that are vastly beyond the abilities of classical physics [2]. What is meant by quantum technologies and quantum effects in biological systems will be discussed together with how this can lead to more effective protection strategies. This will also cover how quantum mechanics is currently exploited in biological applications and theories. The insight given here on the interplay of quantum biology and biological eyesight is put into context finding room in the bigger picture of the interplay of quantum biophysics and the wider bio-physical world of sensory perception. Broadly a lot of words will be used to come to what can be a very broad and unifying thesis on the underlying design principles of sensory perception overall.

Quantum biology is concerned with the experimental and theoretical study of non-trivial quantum phenomena in biological systems, where non-trivial means beyond simple inclusion of phenomenological quantum noise in a primarily classical model, like adapting the Gianpiero and Vitiello approach. Especially for single cell and individual molecule modelling it would be impractical if explicit multiple state quantum models where considered for all biological macromolecules and their interactions. Therefore quasi-classical hybrid models have been chosen to sup at the precise quantum mechanical calculations. Perturbation theory, mean-field descriptions, and stochastic master equations governing the time-evolution of relevant system's operators, is employed within numerical simulations also give one access to probability distributions and averages that help forming a more broad picture of observed quantum effects in biological systems. A key feature of all of the selected models and the calculations described here consider a biological nuclear spin ensemble with a common spectral diffusional motion.

7.1. Magnetoreception in Birds

For millennia birds have captivated the imagination of humans with their biological navigation. Around 50 years ago a new hypothesis was formulated as a specific biophysical model of the bird's compass. This model assumes that a field-dependent mechanism of electron spins generated in magnetically sensitive chemical reactions is used by birds to visualize magnetic directions. Since then, a great deal of experimental and theoretical works has been carried out in different laboratories around the world to validate the model, which led to further refinements and extensions. The distinctive feature of the present stage of the bird's compass model is the need for planar rotation of the direction of the alignment of the dual chemical compass based on correlated product yields of the radical pair reactions involved [25]. Some experimental predictions of the avian compass based on this feature are reviewed, as are their biological implications. A novel way of visualization of this quantum effect based on the apparatus of graph theory is suggested.

The search for ways to understand the navigation of animals and birds has been going on for several millennia. Since the middle of the last century, it has received an impetus as a result of the discovery of complex regularities in the migratory paths of certain species. Were determined the starting points of migration, the bisectors of which stretched to the nesting sites in Canada. After this, the fact of year-by-year regularities in the migratory flows of birds was established. However, only with the establishment of microliterology did it become possible to follow the flight of birds at individual points. Among other things, it was found that migratory birds use the geomagnetic field for orientation. For about 50 years, it has been assumed that the primary mechanism for magnetoreception in birds is connected with magnetization of biogenic magnetite. At the beginning of this century, however, a radical-pair mechanism was proposed as a field-sensitive mechanism of the bird's sense of the magnetic field. It now seems that the aggressive debate between supporters of the new radical-pair mechanism and the adherents of the old hypothesis is finally dying down.

7.2. Olfactory Sensing Mechanisms

Olfaction is the sense that uses the sense of smell [26]. Although declared as immediate and intimate, the mechanism behind it remains one of the systems that science still could not explain [27]. Despite the comparatively well-founded knowledge of the structure of the olfactory receptors (ORs) in the human, the detailed molecular mechanism for privileged bonding of a few ORs of completely different proteins among a total of around 800 different ORs to individual odorants in the presence of significantly high molecular analogs is still an enigma. Decades ago, Amoore suggested that ORs trigger the olfactory system with the binding of an odorant to a specific site. Noticeably, the olfactory system in the mammalians has to discriminate a great variety of scents, ranging from the toxic methyl isocyanide to the lovely fruity smells, with an incredible sensitivity and selectivity. According to Amoore's structure-based models, the scent signature of a substance should stem from the molecule's three-dimensional geometry and, hence, two structurally different chemicals should not smell similarly under ordinary conditions. The olfactory discrimination relies on the idea that the stinking of a particle is due to its blocking of a specific positive or negative template, as described by P. W. Atkins more than three decades ago.

8. Quantum Coherence in Biological Systems

No known function of quantum mechanics-type non-trivially embedded into biological processes has been experimentally observed, maybe some day, explained, but not decodified. Meanwhile, a bunch of facts and results strengthen the point of physical and naturalistic coherence supporting the current interpretation. In any case, observed quantum coherence phenomena may drive the interpretation of biological relentless modeling obliged to include the observed epiphenomena of the coherence. In this sense, explanations of functionality are postexperimental, and experimental results must be taken into account for future explanations. Evolved from photosynthesis or free radicals scavenging defense purpose, coherence materials, molecule distribution fields or effective lattice temperatures and not primarily intrinsic quantum mechanical entities introduce energy regions in the spectra that favor these mechanisms quantitatively analyzed. Anticipation to actual mechanisms may serve as recognition to chance to capture them. Efficient photosynthesis coherently transferred excitations populated spectra in timescales coherent to free radicals scavenging defense relaxation time of the spectrum, proving the biotechnological relevance of coherence in agronomic activators and inhibition. In photosynthesis, it would be employed for bio-engineered regulation of plant exciton transport. This observation should motivate further experiments and modeling of the implications of this work in plant physiology and quantum biochemistry.

9. Implications of Quantum Biophysics in Medicine

1. Introduction: The Role of Quantum Mechanics in Biological Processes

Modern biology, pharmacology, and medicine are deeply rooted in an ever growing quantitative understanding of molecular interactions and organic information processing. At the same time, quantum physics, initially centered on remarkable microscopic phenomena concerning photons, electrons, atoms, and their interactions, has attracted an increasing scientific interest in more complex (often mesoscopic and macroscopic) objects. In the context of all these developments, the role of quantum physics in biology, pharmacology, and medicine deserves a fresh look. Quantum physics has played a significant role in biology almost from the very beginning [1].

On purely formal grounds, it is now accepted that an elementary quantum description must be used to treat the evolution of both classical and quantum systems. However, standard quantum mechanics can hardly be expected to embrace all possible phenomena related to biological processes, which are intrinsically many-body and open systems in permanent contact with their environment. In recent years there have been a variety of theoretical and experimental studies in the interface between the quantum world and living organisms. Even though it is generally agreed that the mere presence of quantum effects is at best an indirect and subtle influence (at very low energy scales), there is a growing awareness of A) the conceptual questions that experiments in this subjects raise, and B) the potential impact of this body of knowledge on a variety of emerging fields (from material science to biotechnology).

9.1. Quantum Imaging Techniques

Quantum imaging addresses the possibility of beating the limits of classical imaging by exploiting the peculiar properties of quantum optical states. There is a vast literature on ghost imaging, together with conjectures about the quantum or classical nature of the effect, which has been dubbed coefficient-only imaging. High-order quantum peculiarities of thermal light and quantum digital imaging are reviewed. Additionally, remarkable quantum illumination is theoretically demonstrated for input separable thermal states, which are largely equivalent to classical thermal light. The term "conventional imaging" is employed to describe the scenario in which an image is obtained using a statistical ensemble of classical incoherently emitting point sources. Conventional imaging performs optimally when the same number of shots per pixel is used [28].

Quantum imaging addresses the possibility of overcoming conventional imaging limits from the viewpoint of quantum optics, by exploiting the peculiar properties of quantum optical states, which are naturally endowed with non-classical correlations. The latter allows quantum imaging protocols to enter into quantum domain and explore quantum resources. The most well-known resources are entangled two-photon states. In particular, for spatially entangled biphotons, sub-shot-noise imaging can be effectively realized. More general, N-photon states create novel opportunities for quantum imaging protocols and applications [29]. A significant effort has been made in the last five years to experimentally overcome conventional imaging, exploring classical correlations of the N-photon state when the second-order spatial correlation function $G(2)(r1, r2)$ is used. The role of high-order correlations of this state and the related sub-Rayleigh regime generally become fruitful.

9.2. Targeted Drug Delivery Systems

The developments of Quantum Biophysics during the last few decades have provided a vital new dimension in the comprehension of individual physiological processes, accommodation, adaptability of single cells, complex systems and of multiple living beings, including the human brain. It implies that exploring the mysterious relationship in living matter lies at the boundary of traditional biology, quantum physics, biophysics, cell biology, quantum chemistry, pharmacology, neurophysiology, nanotechnology and cybernetics. The refinement of the above-mentioned novel areas is critical not only for enhancing the life quality of the current human being, but unavoidably a matter of civilization in the forthcoming era. This text tries to discuss some problems in still very young Quantum Biophysics to evoke the necessary novel innovative research and creation to enhance our possibilities for progress and preservation of our rapidly changing planet and human culture, being so seriously endangered by short-time oriented greed and standard concepts. Personal coherent quantum laser-like oscillation of inside the bifilar DNA long polymers, solitons, which contribute to the fastest transfer of energy and matter is considered among the most notable discoveries in Quantum Biophysics. These series have disclosed an entirely novel insight into bioenergetics, biomedicine geneses of diseases and cytophysiology of the single and multiple systems. Temporal and spatial quantum resonances modify living matter and significantly alter physiological processes. Animal and man brain is frequency analyzers of the external background electromagnetic fields. This result has surprising connections with quantum mind and might make Darwin machine. Proper frequency irradiation can kill leukemia cells and stimulate the differentiation of neurons, speed up superconductivity and improve plants growth. By the non-invasive detection of different cell types, one can timely predict the biochemical alternations well before the appearance of defective immune response of living matter. Biochemical note events can cause time delays and spatial anomalies in brain bioelectronic activities, observable and recordable by the appropriate bioelectronic methods. Successful applications to forensics and neuroscience are reported, concerning the chemical, social and individual behavior. There is enhanced pollutant by the multiplexed acoustics biochemical and bioelectronic methods. The human being can influence its own future behavior by the self-biofeedback method concerning brain potentials. [30][31][32] [30][31]

10. Challenges in Quantum Biophysics Research

With the emerging interest in the burgeoning field of quantum biophysics, the focus is on four of them: First, the discussion is more conceptual than experimental, on the role of quantum physics for biology. Although this is far from the experimental research that is evoked, quantum physics is still a conceptually challenging model of nature that stands in considerable discrepancy to our classical world view. Moreover, it shapes all molecules by its quantum electrodynamics and thus constrains and determines a wealth of biological processes, such as molecular recognition, the workings of proteins and the self-assembling process of the DNA. As for the pros and cons of the modern approach to quantum biophysics, the number of proven facts is still rather small and most of the phenomena that are currently investigated are not directly based on quantum superpositions. Many hypotheses that are formulated today may thus either lack visionary power, because they are not sufficiently ahead of their time, or lack truth, since they are founded on a too naive understanding of quantum mechanics and its interpretation. Nor is it allowed to dismiss a priori certain ideas or thoughts as mere philosophy, since they may serve to constrain and guide future experimentation and theorizing. As an excellent historical example, questioning quantum mechanics can fundamentally shake its naive interpretation and thus lead to alter its apparent conflict with the decidedly classical behavior of certain complex systems. Lastly, it is not a satisfactory approach to claim that such systems are just too large and significantly bio-chemically too hot to clearly exhibit quantum features. The existence of such features must be assessed experimentally, and can neither be disproved formally nor by the absence of a clear physical picture [1].

10.1. Experimental Limitations

A great share of the scientific community contends that quantum mechanics manages to apply consistently to all physical systems. Biology is surely one of the most intriguing fields to explore from such perspective. Concerning the lengths of the distances at which quantum effects might become relevant the following question arises: What are the experimental limitations for the detection of quantum effects in biological systems, given that they occur at all? There are now well established systems, like the photosynthesis in plants, algae and certain bacteria, where quantum effects are non-preliminarily proved to be at the origin of efficient energy transfer [33]. On the other hand, these effects could arise at more subtle levels and in systems where macroscopic quantum effects acting in the nanoscopic scale are involved. Biological systems are very open and complex, and concerning the former one might argue that the presence of a high number of photons to be unavoidably sweated by the macro-system would inhibit the coherent evolution on it with the quantum state of each photon to be detected. Whether the coherent evolution of an open quantum system Hamiltonian with its closed counterpart is at the origin of the appearance of macroscopic quantum effects is under scrutiny among the research community.

Successful islet transplantation requires that a substantial mass of the transplant should quickly engraft and resume insulin production, while the isolated islet immune micro-environment is often subjected to ischemia. Damage associated molecular patterns' (DAMPs) are considered to trigger the innate immune response that could result in the rejection of grafted islets. The present paper investigates, analyzing damages in the adenosine triphosphate molecule pair binding is linked with the ATP release under stress, a quantum oscillator model, damage in a fixed frequency site due to environmental interaction of the first one. Furthermore, the MaxEnt statistical mechanics is exploited to figure out a complex phenomena. It is proved that the latter might represent the trigger of diabetic graft destruction and potentially to pinpoint a way to alleviate this phenomenon.

10.2. Theoretical Challenges

The achievements of biology can seem quite demystified due to statistical physics since the basic building blocks of life are comprised by well known chemicals. In sub-disciplines like theoretical neuroscience, the tendency to draw metaphorical parallels between the brain and quantum mechanics has been perhaps best received. Currently, this tends toward an idea that certain properties of thought or memory can not be explained without reverence to quantum non-locality, thus offering an explanation of consciousness [1].

It is certainly the case that the huge number of individual variables in a biological system supports the use of a quantum-mechanical treatment rather than classical Newtonian dynamics. The apparently counterintuitive nature of quantum mechanics seems to have fostered the rise of a peculiar scientific mythology, such that it has been repeatedly invoked to explain phenomena in diverse fields. These theories exploit the correlation between systems that have become separated in space to argue that in certain situations a measurement of the state of the more-recently-separate system affects that of the other system more quickly than it would do if the systems were purely classical. Early scientific skepticism concerning the properties of entangled states has largely transcended, following an increasing number of experimental tests of Bell inequalities—including a number that would reasonably be agreed to hold a particularly high degree of robustness. There’s currently research examining the dynamics of entangled states that become partially decoherent as a way to understand quantum entanglement in biological processes.

11. Future Directions in Quantum Biophysics

Modern biology, pharmacology, and medicine are deeply rooted in an advancing comprehension of molecular interactions. The prospect of viewing these intricate fields solely as structured aggregates of atoms and molecules is becoming restrictive. After the structure of DNA was determined, the molecular basis of functionality was unveiled, most importantly for genetics. Consequently, the helical double-stranded macromolecule deoxyribonucleic acid is now universally known as ‘the source of life’. However, the working of DNA, the ‘molecular biology par excellence’, alone does not reveal the whole story of life. Ernst Mayr aptly regards this necessary reductionist strategy to understand biology as like seeking understanding of the functions of a TV by performing atomic physics on the TV screen: the TV will instead be understood to catch TV waves.

In an analogous manner, the correct paradigm shift to understand molecular biology is not being sought in molecular biology itself. In recent years, scientific interest has turned to the intricate relationship between molecular biology, the shaping of life by quantum mechanics, and some aspects of electrodynamics which might also play a role. It is by no means the first time that the latter confluence of physical disciplines has drawn the attention of frontal scientists. Erwin Schrödinger, one of the founding fathers of quantum theory and quantum mechanics, anticipated a molecular basis for the characteristics of human heredity (epigenetics), a prediction historically confirmed to be DNA. Amazingly, BSDA is solely based on higher principles of quantum mechanics [1]. It is odd, then, that a theory describing most accurately the physical reality of molecular processes should neglect the predominant role of QM itself - certainly not true for life sciences. The physically realistic control of macromolecular recognition involves a range of complex QM and electrodynamics phenomena shaping all active molecules. PRO and DNA alone possess highly intricate QM and ED relationships which determine their helicity, the workings of the building proteins, and therefore their functions. Concerted action of controlled QM and ED phenomena defines complex biological machineries, such as molecular compasses or polymeric quercesens tackling UV light exposure.

11.1. Interdisciplinary Approaches

Might quantum mechanics play a significant role in biological processes? A rather fundamentally charged dispute, for biology usually has been considered to be too hot, wet, and big for anything genuinely quantum to push its participants around. Nevertheless, vigorous argumentation in both respects is attended from each side of the court. The emerging field of Quantum Biophysics not barely tries to investigate possible forms of entanglement in biological structures, but also aims to trace back the fundamental role of quantum states in the field of biological information processing.

Top-down mutual mechanism modeling could represent a comprehensive approach toward mutual quantum biophysics. Hopefully these mutual models might contribute to gain a more in depth understanding of the versatile ways in which quantum mechanics might influence biological processes. A quite surprising synergy has recently emerged between the natural sciences--more accurately between quantum physics and the life sciences--which has led to the development of Quantum Biophysics. From a holistic perspective, living systems--just like atoms or other smaller creatures--are also subject to the laws of quantum mechanics. Thus, it is merely consequent to ponder on the role of quantum physics in living systems.

11.2. Technological Innovations

Modern pharmacology and drug design depend entirely upon understanding and describing interactions between small molecules and macromolecules involved in biological process and disease. But despite more than half a century’s progress in investigations of these phenomena, there is still lack of clear understanding of these processes and no simple way for their prediction. This is in part due to the inadequate treatment of the many body interactions leading to formation of molecular complexes and of the quantum mechanical effects important to the description of bonding, structure and docking [1].

Recent innovations in the field of biophysics should provide a highly significant acceleration of progress of knowledge in this field. Driven by new opportunities in experimental biophysics and physical chemistry, rapid progress is occurring in the theory and computation of inter- and intramolecular interactions in the context of macromolecular structure and dynamics. New theoretical methodologies are being developed which take account, in a robust and precise quantum mechanical way, of the various effects involved in structure-function relationships.

Methods such as the potential of mean force approach, which take as input the output of quantum chemical calculations on model systems and provide a quantum mechanical description of the potential energy surface for the interaction between a molecule and a macromolecule, now permit the calculation of the binding free energy and the docking of molecules on macromolecules. Stimulated by the numerous examples of the successes of the computations in predicting and analysing various biologically related phenomena, great effort is developing at the interface of quantum mechanics, biophysics and chemistry. The emphasis is both on developing better theoretical descriptions of the relevant systems and on applications to complex, real-life systems. The final goal of the integration and interdisciplinary approach is to understand at a fundamental level the mechanisms of the molecular processes involved in the recognition between molecules of biological and pharmaceutical interest. The benefits accruing from a fundamental comprehension of these processes are likely to be transferable to many areas of science.

12. Ethical Considerations in Quantum Biophysics

Following thorough considerations from physics, quantum biophysics has been deliberated intensively and some first theoretical studies have commenced. One may also expect a series of experiments investigating the impact of possible quantum effects and quantum forces on the structure, behavior, and interaction of biomolecules. Here, to acquire a general overview and to prepare for the field experimental and theoretical studies, a discussion is presented of ethical issues arising in quantum biophysics research at the current early stage.

An issue with a tension field between speculation and the nature of quantum mechanics also offers a fertile ground for the birth of a flood of free speculations of a nature more philosophical than significantly scientific. Hence, it seems to be fair for any open minded and credible scientist, working on this topic, to respond to questions like “Are you a physicist or a philosopher?” or “Are you a scientist or a charlatan?” Therefore, a list of ethical fundamental rules for research in quantum biophysics is given here at the very beginning.

While sharing some basic principles with standard biophysics (quantum biophysics shares the fundamental goals to elucidate the basic principles of biological systems and to deliver radical new insight and technologies of direct benefit to society), quantum biophysics research also opens several novel dimensions and thus creates very special challenges and opportunities in terms of ethical reflection and policy. This brief discussion reviews those weaker and stronger forms related to quantum biophysics research that are under some discussions and might currently apply. Then, attention is turned to the much more intriguing consequences of a world in which quantum physics plays a non-negligible role in the functioning of biological systems and the role of mankind in terms of a reduction of the wave function.

13. Case Studies in Quantum Biophysics

Modern biology, pharmacology and medicine are deeply rooted in a growing understanding of molecular interactions and, more recently, in monomolecular processing. The full knowledge and control of molecular processes would impact all sectors of life science, enabling, for instance, significantly improved imaging and control of complex biological systems. How and when this full understanding will be achieved are fundamental questions, with obvious technological and commercial implications. This paper spurs an interdisciplinary effort involving physics, chemistry and information science, aiming at the identification of future research directions and applications. It is argued that basic information theoretic concepts can offer new and effective tools in characterizing and controlling biological molecular systems, from the cell to the DNA levels [1]. A new non-locality mediated information transfer mechanism in DNA is predicted and its potential biological role discussed.

Biological macromolecules are assumed to be involved in the storage, replication and translation of information. In the heart of this machinery, reduces to mono, bi and, at most, trinucleotides sequences. This information is processed not only in standard numerical and logical operations, but also through interactions along the whole molecule length, possibly implying long-range physical properties of the nucleic acid. This could make quantum mechanical properties of the DNA become non-trivial at such biological scales.

The mathematical modeling of the information exchange between two nucleotides on complementary strands will introduce a non-standard, purely quantum mechanical, communication channel. It enables the transfer and sharing of information between separated nucleotides without any protein mediator—and therefore independently on the nucleotide chain chemical details. This kind of interaction is mediated by the Hamiltonian terms describing the interaction between distinct areas of the electron clouds of the two nucleotides, and occurs without any well defined transfer of energy. Although the basic physics behind this mechanism is rather standard, its biological implications in the DNA context are discussed.

13.1. Case Study 1: Quantum Effects in Photosynthesis

During the first steps of photosynthesis, the energy of impinging solar photons is transformed into electronic excitation energy of the light-harvesting biomolecular complexes. The subsequent energy transfer to the reaction center is understood in terms of exciton quasiparticles which move on a grid of biomolecular sites on typical time scales less than 100 femtoseconds. This energy transfer is described as an incoherent Förster hopping with classical site occupation probabilities, but with quantum mechanically determined rate constants.

Here, the optical 2D photon echo spectra of this complex at ambient temperature in aqueous solution do not provide evidence of any long-lived electronic quantum coherence, but confirm the orthodox view of rapidly decaying electronic quantum coherence on a time scale of 60 fs. The results give no hint that electronic quantum coherence plays any biofunctional role in real photoactive biomolecular complexes. Since this natural energy transfer complex is rather small and has a structurally well defined protein with the distances between bacteriochlorophylls being comparable to other light-harvesting complexes, it is anticipated that this finding is general and directly applies to even larger photoactive biomolecular complexes.

13.2. Case Study 2: Quantum Tunneling in Enzymes

Quantum mechanics is a fundamental physical theory that has been extremely successful in elucidating a wide range of physical phenomena. Despite its remarkable success, the theory is often misunderstood in a plethora of instances especially in popular media. Over the decades, proposals have been made to account for the operation of biochemical systems, in particular, the mechanism by which the genetic material DNA is translated into the macroscopic structures of the body. In the last 15 years, there has been a significant resurgence of interest in the role of quantum mechanics in biological processes. In particular, there has been speculation that quantum-mechanical processes play an important role in biological processes from the scale of molecular structure to biological organisms situated within an ecosystem. Much of this work is motivated by a growing number of experimental results concluding that quantum processes, such as resonance energy transfer, are ubiquitous in biological systems.

The investigation of quantum mechanical processes in biological systems, also known as quantum biophysics, does not intend to cast aside the considerable achievements of biochemistry and physiology. One of the profound insights from biological science is the understanding of the structure and operation of the genetic material DNA, which as a consequence of this knowledge has allowed a wide variety of genetic diseases to be treated. Instead, the paradigm shift that is being considered is that the basic building blocks of the biological machinery are not flat rigid sheets of biomolecules performing classical-like reactions, but rather operate like a fluid that is capable of accessing a wide ensemble of dynamic configurations [34]. From the vantage point of investigating biological systems through the lens of quantum mechanics, a flow diagram of the built-in superstructure of biological knowledge is represented. At the forefront are the biomolecules, those building blocks which make up the living organism and sets the scaffolding of what biology constructs its edifice.

14. Comparative Analysis of Classical and Quantum Models

What is the role of quantum physics in and for biology and a fortiori for biophysics? That quantum physics and the quantum field theory for electrodynamics would play a central role in shaping all molecules, their energetics, and thus all directions of chemistry was clear from the early beginnings of quantum theory. It therefore also determines molecular recognition. Nevertheless, according to usual wisdom, classical physics is deemed sufficient for comprehending the overview of the workings of proteins and DNA. This has several justifications. Broadly, this is because the energy scales of thermal agitation are huge compared with the one among liveliest molecules, and so dephasing and wave-function collapse are prevailing. More practically, as well as excluding dephasing, the complexity of Schrödinger's equation requires too extensive computational resources beyond few--electron model systems. For more comprehensive models, quantum mechanical limits must be placed on system size, truncating the ability to model realistic biophysical systems. Indeed, a criticism of early quantum biology research was that it tended to be speculative, with grand claims based on little theoretical or experimental evidence. Much of the more recent successful research has aimed to counter these arguments [1].

15. Conclusion

There is a growing understanding of molecular interactions central to biological, pharmacological and medical information. Four letters code the amino acids of DNA coding for the proteins and enzymes acting as chemical agents and biochemical catalysts in the genome. Within the biophysics of life, this genetic information is stored and processed using molecular recognition. Recognition is likely to take advantage of the rich electrodynamics of charge and molecular symmetries. Over the last 50 years, one of the most fascinating bodies of knowledge shaping this molecular biology was quantum physics, electrodynamics and statistical physics. Quantum phenomena of superposition, entanglement, dephasing and quantum interference at the microscopic scale build the foundation of the interaction and dynamical behaviour of atoms, molecules, biochemical systems. Intense research in biophysical systems has been rewarded with striking applications in NMR, spectroscopy, chirality recognition, collective molecular phenomena, material sciences and new drugs. In optoelectronics, noise still remains a nuisance. Nevertheless, healthy, living systems offer remarkable advantages and can amplify weak signals below the shot noise and detect.

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