

Quantum Mechanics in Biological Systems: Bridging the Gap Between Physics and Life Sciences

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Abstract:

The discipline of quantum mechanics, which has traditionally been associated with the behavior of subatomic particles, is seeing a growing amount of recognition for its relevance in biological systems. The relatively new field of study known as quantum biology, which explores the ways in which quantum phenomena such as superposition, entanglement, and tunneling manifest themselves in a wide range of biological processes that are of interest. It would appear that quantum mechanics has an impact on the effectiveness and accuracy of the fundamental processes that are necessary for life. These processes include, but are not limited to, photosynthesis, enzyme catalysis, avian navigation, and olfaction. This study, which draws from a variety of disciplines, sheds light on the ways in which quantum effects manifest themselves in intricate biological systems and the potential implications that these effects may have for the development of domains such as medicine, neuroscience, and biotechnology. This is accomplished by bridging the gap that exists between the fields of physics and the areas of biological sciences. A discussion of the challenges that arise when attempting to investigate quantum phenomena in biological settings that are both warm and noisy, as well as the experimental methods that are utilized in order to investigate these effects. At the end of the day, this research not only provides light on the role of quantum mechanics in the genesis of biological processes, but it also opens up new avenues for understanding life on the most fundamental level.

Keywords:

Quantum biology, quantum mechanics, superposition, entanglement, tunneling, biological systems

Introduction

The subatomic particles, such as electrons and photons, have traditionally been the focus of the application of quantum mechanics, a branch of physics that is responsible for understanding the behavior of matter and energy at the smallest scales. Because of its paradoxical principles, which include superposition, entanglement, and tunneling, our perspective on the physical universe has been profoundly altered. This is because of the paradoxical nature of these concepts. A recent body of study, on the other hand, has demonstrated that quantum phenomena may not be confined to the realms of the atomic and subatomic levels. There have been recent findings that have led to the establishment of the field of quantum biology. This field is founded on the concept that quantum mechanics plays a vital role in a range of biological processes. It

is commonly accepted that classical physics is associated with biological systems. This is due to the fact that it enables the comprehension of the macroscopic behavior of cells, tissues, and organisms without the necessity of invoking quantum principles. Quantum effects, on the other hand, are thought to be the cause of the remarkable efficiency and precision of a number of biological processes at the present time. Photographic synthesis, enzyme catalysis, magnetoreception in birds, and even olfactory perception in humans are all examples of these activities. The discovery of quantum coherence, for instance, has demonstrated that biological systems are able to make use of quantum mechanics in environments that are hot, humid, and noisy. This is the case in the case of photosynthesis. In the past, it was believed that delicate quantum states would not be able to withstand these conditions because they were too disruptive. For the purpose of bridging the gap between the fields of physics and life sciences, it is important to investigate the ways in which quantum mechanics can have an impact on biological systems. Our investigation will focus on the ways in which quantum effects such as superposition and tunneling facilitate biological processes at the molecular and cellular levels. We will use examples from quantum biology to illustrate our findings. More specifically, we will utilize these examples to demonstrate how the consequences of quantum mechanics operate. In addition, we will discuss the challenges that are encountered when attempting to explore quantum events in biological contexts, as well as the experimental approaches that are carried out in order to establish the existence of these effects. There is a chance that quantum biology will change our knowledge of life itself, which would result in the provision of new insights into fields such as medicine, neuroscience, and biotechnology. The advancement of quantum biology, which is still underway, allows for the possibility of this happening. This multidisciplinary research is expected to result in the discovery of innovative discoveries and applications at the intersection of the domains of physics and the life sciences. This is something that is anticipated to happen. Integrating the fundamentals of quantum physics with the complex biological systems will be the means by which this objective will be attained.

Quantum Phenomena in Biological Systems

When quantum phenomena were first discovered, it was thought that they could only be found in the microscopic realms of atoms and particles. However, it is now becoming more recognized that these phenomena are essential to a wide range of biological activities. Quantum mechanics is responsible for the introduction of a number of principles, including superposition, entanglement, and tunneling, among others. In spite of the fact that these principles appear to be counterintuitive, it would appear that they improve the efficiency and precision of some biological functions. This is a list of significant quantum phenomena and the roles that they play in biological systems, which are as follows:

1. Superposition in Biological Processes

It is referred to as superposition, and it is an essential component in the operation of certain biological systems. Superposition is the capacity of a quantum system to exist in many states at the same time. Quantum mechanics enables particles to exist in a variety of states simultaneously, in contrast to classical physics, which only permits objects to exist in specific states (such as on or off, 0 or 1) at any given moment. Quantum mechanics allows particles to

exist in a variety of states simultaneously. When it comes to biological systems, it is generally accepted that this phenomenon is at work in processes such as photosynthesis. Photosynthesis is a process that requires the effective transfer of energy between light-harvesting complexes. During the process of photosynthesis, a phenomena known as superposition takes place. This phenomenon allows excitations, which are energy carriers, to simultaneously explore a number of different pathways as they move through protein complexes in the direction of reaction centers. It is because of this quantum behavior that the efficiency of energy transfer is significantly improved. This makes it possible for organisms that are capable of photosynthesis to amass and utilize light energy with an exceptional degree of precision.

2. Quantum Entanglement and Its Biological Implications

When particles become correlated in such a way that the state of one particle is immediately coupled to the state of another particle, even when the two particles are separated by enormous distances, a phenomenon known as quantum entanglement takes place. This phenomenon is a phenomenon that occurs when particles get correlated. Avian navigation is a procedure in which birds make use of the magnetic field of the Earth in order to orient themselves when they are migrating. It has been theorized that the unknown attribute in question plays a role in the process of avian navigation.

One of the hypotheses that claims that the eyes of birds contain proteins that are known as cryptochromes and that, when exposed to light, form radical pairs that are entangled with one another is called the radical pair mechanism. Because these entangled couples are sensitive to the magnetic field of the Earth, birds are able to perceive directional information. This capacity is made possible by the fact that birds are able to sense directional information. This particular kind of quantum sensing makes it possible to travel over enormous distances with pinpoint accuracy, which is a feat that would be difficult for classical systems to explain with such precision. This is because quantum sensing takes advantage of quantum mechanics.

3. Quantum Tunneling in Enzyme Catalysis

Quantum tunneling is a process that occurs when particles are able to overcome energy barriers that, according to the rules of quantum physics, they would not be able to be able to transcend in a classical context. This phenomenon is characterized by the fact that quantum tunneling occurs. This phenomenon is particularly significant in enzyme catalysis because it makes it possible for protons or electrons to "tunnel" past potential energy barriers. As a result, biological reactions are sped up to a far greater extent than what is expected by traditional models.

Through the utilization of quantum tunneling in enzyme reactions, it is possible to lessen the activation energy that is required for the realization of chemical transformations. This enables reactions to take place at higher speeds and at lower temperatures than they would have been able to otherwise. As a result of the fact that proton and electron tunneling contribute to the effectiveness of these essential biological functions, this phenomenon has been discovered in a number of enzymes, such as alcohol dehydrogenase and methylamine dehydrogenase at the same time.

4. Quantum Coherence in Biological Systems

There is a connection between the concept of quantum coherence and the preservation of quantum states over the course of time. It is possible for particles to interfere with one another in either a constructive or destructive manner due to the wave-like nature of particles, which causes this phenomenon to take place. The mechanics of photosynthesis, which include the transfer of energy, are particularly significant in biological systems because of the significance of quantum coherence.

Excitons are able to pass through light-harvesting complexes in a wave-like manner because of the presence of coherence in these complexes. This ensures that energy is transferred effectively even in biological environments that are noisy and hot. Excitons are able to "sample" multiple paths and select the most efficient path to reaction centers as a result of this wave-like behavior, which adds to the practically flawless efficiency of the conversion of photosynthetic energy. Excitons may also be able to select the most effective path to reaction centers.

Photosynthesis and Quantum Coherence

Photosynthesis is a mechanism that allows plants, algae, and certain microorganisms to convert light energy into chemical energy. This transfer of energy occurs in the process of photosynthesis. This process is widely regarded as one of the most effective biological processes that are currently taking place on terrestrial planets. There have been recent research conducted in the field of quantum biology that have suggested that quantum coherence may be responsible, at least in part, for the remarkable efficiency with which energy is transported throughout the process of photosynthesis. The existence of this quantum phenomenon makes it feasible for energy to be transported through light-harvesting complexes with only a minimal degree of loss. This ensures that the conversion of solar energy into chemical energy is practically faultless.

1. Light-Harvesting Complexes and Energy Transfer

During the first stage of the process of photosynthesis, the light-harvesting complexes (LHCs) are responsible for the absorption of photons, which are particles of light. Chlorophyll and other pigments are responsible for this absorption. Through the process of acquiring energy, electrons get excited, which ultimately leads to the production of a mobile energy carrier that is referred to as an exciton. It is necessary for the exciton to first travel through a network of pigments that are contained within the LHCs before it can arrive at the reaction center. When the energy reaches its destination, it is put to use in the process of initiating chemical processes, which ultimately lead to the synthesis of glucose.

The conventional description specifies that the exciton would migrate in a haphazard manner from one hue to another until it reached the reaction center. This would continue until it reached the reaction center. On the other hand, this process would be slow and ineffective, especially when taking into consideration the noisy and hot environment that biological systems frequently find themselves in. Another explanation for the efficient and speedy transfer of energy is provided by quantum coherence, which provides an alternative interpretation of the phenomenon by providing an alternative interpretation.

2. Quantum Coherence and Superposition in Energy Transfer

Quantum coherence is the term used to describe the phenomenon that occurs when a system contains a number of different quantum states at the same time simultaneously. When it comes to the process of photosynthesis, the exciton that is generated as a consequence of photon absorption does not go in a single way back and forth to the reaction center. The exciton, on the other hand, is able to reside in a superposition of many states due to quantum coherence. This allows it to simultaneously explore all of the various paths that are present across the pigment network.

With the help of this quantum activity, the exciton is able to "sample" a number of different paths and choose the one that is the most effective for the transfer of energy. Because of this phenomena, which is frequently referred to as quantum walk, it is possible to transfer energy at a far faster rate than what would be possible with classical hopping. It is possible for the exciton to maintain its coherence in spite of the thermal noise that is often present in biological environments. This ensures that energy is transferred with a minimum of losses.

3. Experimental Evidence of Quantum Coherence in Photosynthesis

Two-dimensional electronic spectroscopy was utilized by researchers in 2007 in order to explore the kinetics of energy transfer in light-harvesting complexes. The experimental evidence for quantum coherence in photosynthesis was found for the very first time at this particular moment. Researchers were able to see oscillations in the process of energy transfer by utilizing this method. This gave evidence that quantum coherence was, in fact, engaged in the process. Energy transfer is a process that involves the transfer of energy.

In contrast to the behavior of classical particles, these oscillations suggest that excitons continue to exist in a coherent superposition of states as they move over the pigment network. This is in contrast to the behavior of classical particles with which they behave. As a result of the disruptive effects of thermal noise, it was previously believed that quantum coherence could not exist in photosynthetic complexes even at healthy temperatures. However, it has been demonstrated that quantum coherence can exist in these complexes. According to the findings of other studies, this is correct.

4. Efficiency of Energy Transfer

A significant portion of the remarkable effectiveness of photosynthesis can be traced, at least in part, to the part that quantum coherence plays in the process. Under some conditions, up to 95% of the light energy that is absorbed is converted into chemical energy, with only a small amount of energy being lost. This is a remarkable achievement. This is because photosynthetic organisms are able to maximize their energy collection in habitats with fluctuating light, such as those that are found in dense woods or underwater environments. This is because of the effectiveness of their photosynthesis process. Its effectiveness is absolutely necessary for photosynthesis in organisms.

When it comes to biological systems, the fact that quantum coherence may be maintained over extremely extended periods of time runs counter to the predictions made by conventional physics. Under normal circumstances, decoherence, which refers to the loss of quantum coherence, would proceed at a rapid speed in surroundings that are very loud. It seems that photosynthetic systems have developed mechanisms to protect quantum coherence, which

enables them to function at a level of efficiency that is close to the quantum limit. This is the case because quantum coherence is a fundamental property of quantum systems.

Conclusion

The study of quantum mechanics in biological systems has led to significant advancements in our understanding of life at the molecular level. These advancements have been made possible by the quantum mechanics research. Quantum phenomena such as superposition, entanglement, tunneling, and coherence, which were for a long time thought to be exclusive to subatomic particles, are now recognized as components that play an important role in a wide range of biological processes. The processes that fall under this category include, amongst others, olfaction, enzyme catalysis, photosynthesis, and navigation by birds. These findings give light on the manner in which quantum mechanics improves the efficiency and precision of biological functions. They do this by bridging the gap between the seemingly different fields of physics and life sciences known as the physical sciences and the biological sciences. Not only does the multidisciplinary subject of quantum biology improve our understanding of biological systems, but it also prepares the way for fresh approaches to innovation in the disciplines of medicine, neurology, and biotechnology all around the world. Quantum biology is a field that is gaining popularity. In the event that scientists are able to comprehend the concept of quantum effects and acquire the skills necessary to utilize them, they have the potential to revolutionize a wide range of sectors, such as the production of medications, the harvesting of energy, and the development of sensory technologies. Nevertheless, when attempting to examine quantum events in the warm and noisy environments of biological systems, there are hurdles that need to be addressed. During the process of overcoming these challenges, developments in experimental techniques are providing assistance in the process. Furthermore, as research in quantum biology continues to grow, it is likely that we may gain additional insights into the quantum nature of life. It has been demonstrated that the discipline of quantum mechanics is a fundamental component of biology, and the ongoing exploration of this subject has the potential to bring about a transformation in both of these fields. Within the realm of understanding life at its most fundamental level, quantum biology is at the forefront of the field. It is able to achieve this by bridging the gap between the fields of physics and the biological sciences, and it has the potential to have applications that are revolutionary in a wide variety of scientific fields.

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