Quantum biological tunnelling for electron transfer

Quantum biological tunneling refers to a quantum mechanical phenomenon in which electrons or other particles move through a barrier or potential energy barrier in a biological system without having enough classical energy to overcome that barrier. It plays a crucial role in various biochemical and biological processes, especially in electron transfer reactions. Here are key points related to quantum biological tunneling for electron transfer:

Electron Transfer Reactions: Electron transfer is a fundamental process in biochemistry and biology, occurring in processes such as photosynthesis, cellular respiration, and enzymatic reactions. During electron transfer, electrons move from one molecule or atom to another, typically through a series of redox reactions.

Classical vs. Quantum Behavior: In classical physics, electrons would require sufficient thermal energy to overcome an energy barrier and transfer between molecules. However, in biological systems, many electron transfer reactions happen at rates much faster than classical physics would predict. Quantum biological tunneling provides an explanation for this phenomenon.

Quantum Tunneling: Quantum tunneling occurs because electrons are not strictly particles with definite positions and energies. Instead, they exhibit wave-like properties described by quantum mechanics. When an electron encounters a potential energy barrier, there is a finite probability that it can “tunnel” through the barrier, bypassing the need for classical energy to overcome it.

Distance and Barrier Height: The probability of quantum tunneling depends on several factors, including the distance the electron needs to travel and the height and width of the energy barrier. Shorter distances and lower and narrower barriers increase the likelihood of tunneling.

Biological Examples: Quantum biological tunneling is observed in various biological processes:

Photosynthesis: During photosynthesis, electrons move through a series of proteins and molecules in the photosynthetic electron transport chain. Quantum tunneling is believed to play a role in facilitating the rapid and efficient transfer of electrons within this chain. Enzymatic Reactions: Enzymes, which are biological catalysts, often facilitate electron transfer reactions. Quantum tunneling can enhance the rate at which electrons move between enzyme cofactors and substrates. Respiration: In cellular respiration, electrons are transferred along the mitochondrial electron transport chain. Quantum tunneling can contribute to the efficiency of this process. Biological Significance: Quantum biological tunneling is essential for maintaining the efficiency of many biological processes. It allows for rapid electron transfer even at low temperatures and under conditions where classical energy transfer would be inefficient.

Experimental Evidence: The detection of quantum tunneling in biological systems can be challenging, as it often involves subtle effects. Researchers use various techniques, including kinetic isotope effects and computational simulations, to provide evidence for the involvement of quantum tunneling in specific reactions.

Ongoing Research: Quantum biological tunneling is an active area of research, with scientists working to better understand its role in various biological processes and to explore its implications for bioenergetics and enzyme catalysis.

In summary, quantum biological tunneling for electron transfer is a fascinating quantum mechanical phenomenon that enables efficient electron transfer reactions in biological systems, contributing to the functioning of essential biological processes. It highlights the intricate interplay between quantum physics and biology.

Quantum biological tunneling for electron transfer is involved in controlling essential functions for life such as cellular respiration and homeostasis. Understanding and controlling the quantum effects in biology has the potential to modulate biological functions. Here we merge wireless nano-electrochemical tools with cancer cells for control over electron transfer to trigger cancer cell death. Gold bipolar nanoelectrodes functionalized with redox-active cytochrome c and a redox mediator zinc porphyrin are developed as electric-field-stimulating bio-actuators, termed bio-nanoantennae. We show that a remote electrical input regulates electron transport between these redox molecules, which results in quantum biological tunneling for electron transfer to trigger apoptosis in patient-derived cancer cells in a selective manner. Transcriptomics data show that the electric-field-induced bio-nanoantenna targets the cancer cells in a unique manner, representing electrically induced control of molecular signaling. The work shows the potential of quantum-based medical diagnostics and treatments [1].

[1]
Jain A, Gosling J, Liu S, Wang H, Stone EM, Chakraborty S, Jayaraman PS, Smith S, Amabilino DB, Fromhold M, Long YT, Pérez-García L, Turyanska L, Rahman R, Rawson FJ. Wireless electrical-molecular quantum signalling for cancer cell apoptosis. Nat Nanotechnol. 2023 Sep 14. doi: 10.1038/s41565-023-01496-y. Epub ahead of print. PMID: 37709951.