RESEARCH

# DNA quantum capabilities and their potential impact on different scientific fields

Dana Flavin[1] MD, Massimo Fioranelli[1] MD, Maria Luisa Garo[2], MSc, Maria Grazia Roccia[1] MD

**Flavin D, Fioranelli M, Garo M L, Roccia M G. DNA quantum capabilities and their potential impact on different scientific fields. J Mod Appl Phys. 2023; 6(4):1-8.**

## ABSTRACT

The multifaceted nature of DNA has always been the subject of extensive research and scientific investigation, as the complex DNA structure has profound implications for many scientific fields from chemistry to physics, including quantum physics. This article focuses to present an overview on the intricate science of quantum DNA aiming to deepen the current knowledge of the diverse role of quantum DNA in various aspects of scientific disciplines. Starting from an analysis of the structural features of DNA, such as its torus-like shape during transcription that allows additional energy from spinor waves, the chiral shape of DNA and its possible role in water splitting and energy dynamics, and the various functions of DNA, ranging from information storage to energy utilization to water-mediated communication, the broad field of quantum DNA nature is illuminated.

**Key Words:** *DNA structure; Quantum entanglement; Quantum biology; Quantum phenomena*

## INTRODUCTION

DNA, the basic building block of life, has fascinated scientists for decades [1]. Its intricate structure and diverse properties span a wide range of scientific disciplines, including electrical engineering, chemistry, biochemistry, and physics, including quantum physics [2]. DNA is indeed a complex system with multiple functions. It serves as an information storage and utilization mechanism, and there is considerable evidence that message transmission also occurs in the water component of DNA. The integration of frequencies, magnetic fields, and vortices adds complexity in understanding how DNA works. Recent research has highlighted the remarkable potential of DNA as a medium for quantum messaging both within and beyond its physical limits [3].

Crucial to DNA's quantum capabilities are its unique chemical interactions and the intriguing interplay between classical and quantum phenomena. Within the double helix, neighboring sites become entangled, enabling the exchange of information maintaining the ordering of the elementary components of the system through spontaneous breakdown of symmetry [4].

This quantum entanglement/correlation can propagate along the DNA chain, allowing different sections of DNA to interact like a complex computer system [5]. Furthermore, proteins in DNA provide additional gateways for quantum information processing [6].

The helical structure of DNA, which resembles a twisted torus, holds significant energy potential and plays a critical role in information enhancement, including supporting photosynthesis in plants [7]. Chiral formations found in DNA and other natural systems enhance information transfer, suggesting that the helical structure serves as a channel for both quantum transfer and water-splitting processes. The integration of photoisomerizable units into DNA strands to create photosensitive nucleic acids can be used to develop functional devices such as machines, origami structures, and ion channels, as well as environmentally safe 'smart' materials such as nanoparticle aggregates and hydrogels [8-11].

The composition of DNA contains transition metals, crystals, and other elements that increase its electrical conductivity and resemble a scaffold [12]. These components are critical for both electrical conductivity and quantum transfer within DNA [13,14]. In addition, magnetic fields affect the motion of charged particles and create magnetic vortices that can enable the transfer of quantum information [15].

Apparently, DNA also transfers quantum information through photons rather than relying solely on electron interactions [16]. Spiraling photons in DNA are reflected from minerals, metals, and hexagonal structures, creating photon and magnetic vortices that transmit quantum information [17]. Photons responded to the presence of DNA by changing their patterns and aligning in a

---

[1] *Department of Human Sciences, Guglielmo Marconi University, Via Plinio, 44, 00193 Rome, Italy.*

[2] *Istituto Terapie Sistemiche Integrate, Casa di Cura Sanatrix, Via di Trasone, 6, 00199, Rome, Italy.*

*Correspondence: Maria Luisa Garo, Istituto Terapie Sistemiche Integrate, Casa di Cura Sanatrix, Via di Trasone, 6, 00199, Rome, Italy. E-mail: marilu.garo@gmail.com*

*Received:- 25 Oct, 2023, Manuscript No. puljmap-23-6844; Editor assigned:- 27 Oct, 2023, Pre-QC No. puljmap-23-6844 (PQ); Reviewed:- 29 Oct, 2023, QC No. puljmap-23-6844 (Q); Revised:- 1 Nov, 2023, Manuscript No. puljmap-23-6844 (R); Published:- 10 Nov 2023, DOI: 10.37532/puljmap.2023.6(4);1-8*

particular way, showing the direct influence of DNA on photons. Photons serve as qubits in quantum communication networks and can play a crucial role in implementing quantum key distribution and connecting quantum networks [18]. The purpose of this article is to introduce some aspects of the quantum nature of DNA and to show that these properties of DNA are potentially relevant to many sciences.

## Genes Detect Similarities

A recent study shows that genes can recognize and coordinate with other genes with similar patterns of chemical bases [19]. This recognition process plays an important role in homologous recombination, in which DNA molecules exchange genetic information. The researchers observed that long strands of DNA containing hundreds of base pairs can recognize each other even without the involvement of proteins [20]. Understanding this mechanism could have implications for genetic diseases, ageing and advances in biotechnology and gene therapy. Further experiments are underway to study these interactions and their effects on living cells.

A better understanding of how DNA recognizes and interacts with other DNA molecules is critical and could have implications for fields such as genetics, biotechnology, and medicine. DNA duplexes can recognize each other's sequence homology without single-stranded elements or proteins. The researchers observed the spontaneous separation of two types of DNA within each spherulite, demonstrating that recognition of nucleotide sequences between double helices separated by water occurs in the absence of proteins [21]. The study provides experimental evidence and discusses possible mechanisms for remote recognition of homologous DNAs [22].

However, it does not mention that genes are able to remotely recognize similarities without proteins or other biological molecules assisting this process. A similar study provides a molecular mechanism in which local DNA-DNA interactions that depend on the orientation of the helix provide a potential mechanism for stabilizing the experimentally observed pairing of much longer homologous DNAs [23]. The study suggests an atomically detailed local picture relevant to certain aspects of DNA condensation or aggregation.

## DNA splitting water

Crystals are also found in the basic structure of DNA, as are liquid crystals as part of the water in DNA. We can believe the DNA as a Kagome lattice, an intriguing and rich platform for studying the intertwining of topology, electron correlation, and magnetism, which allows quantum transfer at room temperature [24-26].

The water in DNA is in clathrates, hexagonal and pentagonal liquid crystals that transfer additional frequencies generated in DNA [27]. The structured water in the cells and in the DNA apparently acts like a battery itself, with negative parts of the DNA binding hydrogen ($H+$) and allowing a separate negative charge on the hydroxyl part of the water [28-30].

DNA also controls the structural properties of the catalyst, which in turn plays a key role in water splitting. Although hydrogen is considered the ultimate fuel, its efficient production remains a challenge [31, 32]. The chiral nature of DNA and its possible involvement in water splitting are currently under investigation; indeed, if confirmed, this intriguing concept could have implications for energy production in replication and transcription processes [33].

A DNA-based chiral system at the electrode may provide control over the spin alignment of electrons transferred between the substrate and the electrolyte, allowing efficient formation of the triplet ground state of the oxygen molecule during the water-splitting process [34]. This suggests that a chiral system can be used on the electrode to control the spin alignment of the electrons transferred between the substrate and the electrolyte during the water-splitting process.

Singh describe the use of genomic DNA-mediated synthetic route to boost the electro catalytic Oxygen Evolution Reaction (OER) and Hydrogen Evolution Reaction (HER) to control the synthesis of a porous $Cu_2(OH)PO_4/Co_3(PO_4)_2{\cdot}8H_2O$ composite structure in the shape of a rolling pin showing that the porous $Cu_2(OH)PO_4/Co_3(PO_4)_2{\cdot}8H_2O$ rolling pin composite disseminated faster kinetics towards both OER and HER activities with lower overpotentials [35].

The DNA biomolecules controlled and stabilized the nucleation and development of the composite. As a bifunctional catalyst, the as-prepared catalyst exhibited high electrocatalytic activity for both OER and hydrogen evolution reaction HER. The DNA acted as an active binder between the catalyst and the electrode and also controlled the morphology of the nanostructured materials [36].

Recent developments in DNA metallization strategies suggest that DNA has significant potential for electrocatalytic water splitting due to its ability to interact with different types of metal ions and form stable metal-DNA self-assemblies [37]. This could lead to the development of more efficient and cost-effective electrocatalysts for water splitting, a key process for hydrogen production.

The discovery of a new family of DNA-like inorganic metal-free structures called XYP (X = Si, Ge, Sn; Y = Cl, Br, I; P = Phosphorus), which have a DNA-like double helix structure with semiconducting properties, has shown that they have potential applications in photocatalytic water splitting and high-speed electronic devices [38].

This opens new avenues for research in the field of inorganic DNA-like nanomaterials. These structures were studied using first-principal calculations and were found to be semiconductors with band gaps at wavelengths of 419nm -561 nm, indicating semiconducting absorption in the visible spectral region [38].

In another study, the vibrational modes of the deoxyribose phosphodiester backbone of DNA and their interactions with the aqueous interfacial environment were investigated using 2D IR spectroscopy on a femto- to pico-second time scale [39].

These results may be useful in developing new techniques to study the structure and dynamics of DNA and its interactions with water molecules. The study may also help to understand the ultrafast processes that occur in the backbone structure of hydrated DNA, which is important for the structural integrity of DNA.

McDermott report the discovery of a chiral spine of hydration surrounding DNA [40]. This is a chiral superstructure of water molecules interacting with DNA (Figure 1).

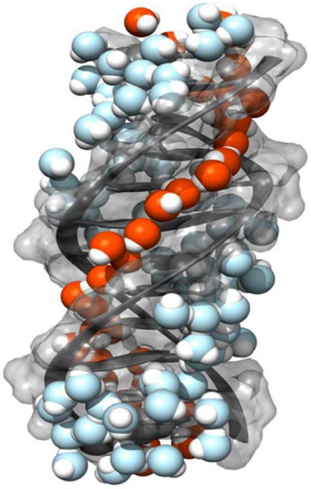

Figure 1) *Illustrates the arrangement of water molecules in the minor groove (shown in red) and the major groove (shown in blue) of the double-stranded oligonucleotide* CGCAAATTTGCG *during a Molecular Dynamics simulation (MD). In this context, the water molecules in the minor groove show a significantly higher degree of order along the DNA axis compared to the water molecules in the major groove. This observation implies that chiral Sum Frequency Generation (SFG) measurements can selectively probe the hydration spine within the minor groove without the need for additional labelling techniques. Reprinted with permission from ref. [37].*

In this study, chiral nonlinear vibrational spectroscopy was used to observe the chiral water superstructure in solution at ambient conditions. The chiral nature of the water superstructure makes it possible to directly determine and characterize the hydrogen-bonding strength of water molecules in biological environments in general. The technique could provide a general label-free method for studying local water structure in biological systems. In addition, they discuss the potential biological function of the chiral water superstructure and the implications of the discovery for studying the solvation structure of DNA under different conditions - providing new insights into the hydration environment of DNA and water in biological environments.

**DNA entanglement**

DNA is a chemical complex consisting of two long molecules arranged in a spiral and is found in all prokaryotic and eukaryotic cells (and some viruses) [41]. It has permeated all sciences from the beginning, thanks to its diverse properties, which include electrical, chemical, biochemical, and finally physic domains, including quantum physics. Starting from the electrical conductivity detected in DNA and enhancing the consideration of the chemical properties of DNA, we can assess how some of the basic chemical structures that emit or reflect frequencies such as hexagonal found in guanine and cytosine, as well as in water, are also considered to be the basis for the superconductivity of electrons in vitro [33].

When considering DNA relationships between electron clouds within the double helix, it is said that these relationships are governed by van der Waals forces. In 1984, Chou in a model related to DNA "breathing" and its interchain hydrogen bonds and designed to calculate the low-frequency modes in DNA molecules, showed that low-frequency wavenumber is in very good agreement with the observed value, hypothesizing that the low-frequency peak for DNA molecules might originate from the kind of intramolecular motion, suggesting that this internal motion may be responsible for the vibrations observed in DNA and thus with relevant implications for understanding the biological functions of DNA [42, 43].

Biological interactions, usually explained based on chemically mediated covalent and electrostatic forces, imply that biological reactions are strictly local and linear. However, within cells, biochemical reactions occur as if in a test tube, and chemical theory is insufficient to explain the molecular interactions that occur in complex structures, especially water, as well as in electromagnetic and gravitational fields [44,45].

According to Adey (1988), glycoproteins on the cell surface can serve as antennas for electromagnetic signals [44]. After transmission across the membrane, the signal is relayed to the cytoplasm by cytoskeletal-mediated processes, which in turn may involve electromagnetic processes [46]. This different approach leads to the idea that the biochemical reaction in DNA can be viewed as a biophysical event in which classical and quantum physics coexist.

According to the recent literature, there are many other potential 'gateways' for quantum information in proteins. Neighboring sites have been shown to act according to the principle of quantum entanglement (i.e., a phenomenon in which two particles are connected in such a way that the state of one depends on the state of the other, regardless of the distance between them) and exchange information about each other, with sites able to detect influences from neighbors in the DNA chain, other cells, membranes, water, and more [24].

Quantum DNA entanglement may play a crucial role in adaptative mutation and gene expression. Harney (2020) showed that the tightly packed chromatin, in which DNA strands are efficiently stored, not only allows gene expression by epigenetic modifiers near neighboring strands, but also allows gene expression by quantum entanglement of epigenetic modifiers [47]. A recent study proposed a quantum mechanical model of adaptive mutation based on the implications of open quantum systems theory.

Ghasemi considered the mRNA-DNA system as an entangled bipartite system (a pair of entangled qubits, each coupled to a specific reservoir) and demonstrated the role of environmentally supported quantum progression of adaptive mutations and hypothesized that random point mutations in DNA can be stabilized and controlled by the environment through entanglement with mRNA [48].

Reiner proposed the existence of an additional quantum physical layer of epigenetics that also operates under environmental conditions and involves coherent charge transfer along overlapping pi-orbitals of DNA bases and chirality-induced spin selectivity. They showed that charge transfer by quantum tunneling induced by overlapping orbitals leads to charge delocalization along several neighbouring bases, which can even be extended by classical (non-quantum) electron hopping.

This charge transfer is disrupted when one or more bases are flipped out of the double strand, e.g., by DNA-modifying enzymes. Charge delocalization can alter the recognition of DNA by proteins directly or indirectly through structural changes in DNA.

Chirality-induced spin selectivity filters electrons according to their spin along the DNA and is thus not only an indicator of quantum coherence but can also affect DNA binding properties [49].

DNA quantum entanglement opens the doors for many applications, such as quantum computing, cryptography, or even computing without computing [50,51]. This last is a newer, less powerful approach in which the more traditional method of using or simulating DNA activity can be replaced by DNA inactivity to solve complex problems [52]. DNA quantum entanglement can indeed provide unbreakable algorithms and additional security levels [53,54].

### DNA information transfer

In DNA, magnetic fields cause electrically charged particles to spin in a circular or spiral path and form magnetic vortices [55]. The spiral shape or structure of DNA appears to be responsible for the amplification of information. If a torus were spirally twisted, as DNA is, it would theoretically carry enormous energy [56]. This is what it looks like in DNA during transcription, where DNA helical structure acts like a spiraling torus [57].

This particular structure is also seen in areas on Earth where there is a high-energy field. The spiral structure is universal in all living matter and promotes growth. In plants, it is important for the instantaneous transfer of photons in the plant for photosynthesis [58]. An example of the structural influence is research at Berkeley Lab in 2019 showing an information amplifying effect in spiral chiral crystals [59]. The quantum transmission to and from DNA apparently comes from the spiral frequencies reflected from photons on minerals, metals, and even the hexagonal structures of DNA [60].

These spiral frequencies are possibly produced by the oscillations in DNA that cause the photons to take on a shape allowing quantum information to be sent and received instantaneously in a quantum field [61]. They may be generated in an elliptical shape as the DNA oscillates throughout the chain, throwing off the photons. If they were entangled, as particles or waves, they would be seen or detected by their complementary receiver at the same time [62].

The vortices of these frequencies, which spin in an elliptical or parabolic rotation due to the oscillation of the DNA, complement the opposite strands, but not the parallel frequencies, and are constantly in motion, alternating and oscillating in a vortex direction or structure [63]. They are spiraling photons from the oscillation of all DNA. Within these frequencies, the vortices are quantum messages which seems to be a consequence of frequencies, not electrons [64].

The DNA braided structure such as a Kagome allows quantum transmission at room temperature. For this reason, temperature does not play a role in this context and there is no gravity or friction to interfere. DNA generates a longitudinal wave along the magnetic field vector, and the calculated frequencies are consistent with biophoton radiation.

The double helix structure of DNA optimizes the efficiency, which can be explained by the vortex model that also contributes to the understanding of the structures of the nucleus and cellular communication. In this interdisciplinary understanding, potential vortices play a crucial role in scalar waves. These potential vortices enable miniaturization and high information density. In addition, the magnetic scalar wave can store and transmit genetic information. Most importantly, the wave itself provides the energy for chemical processes.

According to Mihelic spin-filtering of the DNA double helix can provide the measurement that determines the transition between coherent and decoherent (or Cooper pair electrons and Dirac pair electrons) when those electrons are aligned far enough along the length of the DNA molecule to develop enough “spin motive force” to be filtered out of the conduction path, then the simultaneous Gram-Schmidt transition from coherent to decoherent can change the DNA proportions on either side of the base pair and the base pair will rotate, disrupting the coherent conduction path along the length of the DNA molecule [65].

A vortex formed in a superconductor-semiconductor junction can be considered as a Majorana fermion quasiparticle that allows the C2 endo/C3 endo to reverse the deoxyribose portion of the DNA molecule. This vortex is believed to be a three-dimensional expression of the electron spin.

Transition metals, including ruthenium and even platinum and gold, have been found in DNA. These elements generally enhance the electrically conductive properties [66]. The trace elements, metals, and crystals in DNA are scattered throughout the DNA like a scaffold. They appear to be important for electrical conduction in DNA and for quantum transmission [67]. Although DNA has been shown to enhance electrical conduction and chemical exchange, it is also active through quanta [68]. DNA appears to send and perhaps receive quantum information through photons, rather than through an interaction of electrons [69].

The magnetic vortices seem to be able to reverse their magnetic fields with circular light, possibly photon light- their angular momentum that acts like a magnetic field and shifts the vortices [70]. Some claim that the spirals are amplified by the magnetic fields of DNA: these spiral frequencies are said to produce waves of photons that can be scalar and appear to operate via quantum mechanics or, as Einstein called it, "spooky" [71].

The messaging could be instantaneous and transmits information from the cell's DNA to other cells, the pineal gland, and the entire body. Frequencies in DNA can also be measured in the DNA of chromosomes, and although phonon frequencies have been recorded from the nucleotides in DNA, as far as we know they are not relevant in DNA for the transmission of quantum information, but rather for its internal computer-like activity.

### Role in quantum computing

DNA computing is a fascinating discipline that aims to harness single molecules for computation at the nanoscopic level [72]. This fascinating field is of great interest to researchers in both computer science and biology because it harnesses the inherent capabilities of DNA molecules for computation. With their unprecedented and remarkably high memory density, DNA computing approaches offer promising solutions to a wide range of combinatorial problems. Discover the ground-breaking world of DNA computing and explore its potential and applications is an exciting topic. To that end, researchers are exploring new methods for testing computational chips that are faster and more efficient than current methods.

The methods use ideas from DNA and quantum computing to find the best way to test the chip [73]. Singh demonstrated that after implementing a prototype algorithm called DATPG for testing very large integration circuits developed using the properties of DNA computing, the effectiveness of the algorithm in terms of quality of results, requirements of CPU, error detection, and number of iterations was extremely high compared to some existing other approaches such as exhaustive search and genetic algorithms.

In fact, the algorithm indeed required only $\sqrt{N}$ iterations to find the desired test vector, while classical computing requires $N/2$ iterations, where N was the total number of vectors [73]. The results show that the new methods are better at detecting problems in the chip and require less time and effort.

This could be used to make better computer chips that work more reliably and efficiently. The electronic and magnetic properties of DNA structures doped with metal ions such as Gd, La, Cu, Zn, and Au can cover the problem of classical and quantum transport in biological systems and the possible use of DNA-based systems in electronic and magnetic devices and biosensor applications [74].

Extrapolation of DNA structures and the ability to operate in the quantum domain is one of the most exciting developments in the field of natural computing [75]. This process uses DNA molecules instead of traditional silicon-based computing technologies. It has the potential to revolutionize computing by enabling massive parallel processing and solving complex problems that are difficult or impossible for conventional computers to solve.

Indeed, DNA quantum computing has a number of advantages ranging from high memory capacity, energy efficiency, and massively parallel computing to its impact on various fields such as Big Data, cloud computing, or nanotechnology, and provides essential support in the field of life sciences for simulating biomolecules and supporting machine learning approaches in medicine, aid in solving drug discovery problems (e.g. protein folding or molecular docking), or fastening the process toward personalized medicine [76-79].

Nevertheless, the implementation of DNA quantum computing appears difficult due to challenges related to DNA chemistry, error probability, and cost, as well as high susceptibility to decoherence phenomena, especially when applied in non-biological quantum systems [76, 50].

## CONCLUSION

If we follow the interactions in DNA with its structure, vibrations, photons, and frequencies, we see a natural quantum messaging or quantum logic activity.

Overall, current evidence shows that:

1. The helical structure of DNA, which resembles a twisted torus, holds significant energy potential, and plays a critical role in information enhancement, including supporting photosynthesis in plants.
2. Within the double helix, neighboring sites become entangled, enabling the exchange of information that can propagate along the DNA chain, allowing different sections of DNA to interact like a complex computer system;
3. Proteins in DNA provide additional gateways for quantum information processing.
4. Chiral formations found in DNA and other natural systems enhance information transfer, suggesting that the helical structure serves as a channel for quantum transfer.
5. Transition metals, crystals, and other elements that compose DNA increase its electrical conductivity so that it resembles a scaffold and are critical for both electrical conductivity and quantum transfer within DNA.
6. Magnetic fields affect the motion of charged particles and create magnetic vortices that can enable the transfer of quantum information.

Exploring the potential quantum capabilities of DNA is a fascinating area within quantum biology. While the structure and properties of DNA have intrigued scientists, the extent of its quantum capabilities is still under investigation. Some studies suggest that quantum phenomena such as entanglement and coherence may play a role in how DNA works. However, the field is still growing, and many claims are speculative.

DNA quantum biology has relevant effects in many other disciplines outside the mere biological field. Quantum computing, cryptography, storage and management of big data, and nanomaterials developments are some examples of possible DNA quantum applications. Nevertheless, the current evidence appears so large as heterogeneous. Further research is needed to fully understand the quantum aspects of DNA and their effects on cellular processes.

## REFERENCES

1. Hofer A, Crona M, Logan DT, et al. DNA building blocks: keeping control of manufacture. 2012; 47(1):50-63.
2. Slocombe L, Sacchi M, Al-Khalili J. An open quantum systems approach to proton tunnelling in DNA. Comm Phy. 2022; 5(1):109.
3. Marken JP, Murray RM. Addressable and adaptable intercellular communication via DNA messaging. N Com. 2023; 14(1):2358.
4. Partridge H, Hallam G. The double helix: A personal account of the discovery of the structure of [the information professional's] DNA.
5. Tulub AA, Stefanov VE. Triplet–singlet spin communication between DNA nucleotides serves the basis for quantum computing. 2007; 436(1-3):258-62.
6. Ugya AY, Meguellati K. Quantum technology a tool for sequencing of the ratio DSS/DNA modifications for the development of new DNA-binding proteins. 2022; 9(1):308-23.
7. Wang C, O'Hagan MP, Li Z, et al. Photoresponsive DNA materials and their applications. 2022;51(2):720-60.
8. Cecconello A, Besteiro LV, Govorov AO, et al. Chiroplasmonic DNA-based nanostructures. 2017;

2(9):1-9.

9. Kuzyk A, Schreiber R, Zhang H, et al. Reconfigurable 3D plasmonic metamolecules. Nat Mater. 2014;13:862-66.
10. Shen X, Song C, Wang J, et al. Rolling up gold nanoparticle-dressed DNA origami into three-dimensional plasmonic chiral nanostructures. J Am Chem Soc. 2012;134:146-49.
11. Li F, Tang J, Geng J, et al. Polymeric DNA hydrogel: Design, synthesis and applications. 2019.
12. Metcalfe C, Thomas JA. Kinetically inert transition metal complexes that reversibly bind to DNA. Chem. Soc. Rev. 2003; 32:215-24.
13. Hematpour N, Ahadpour S, Behnia S. Presence of dynamics of quantum dots in the digital signature using DNA alphabet and chaotic S-box. 2021; 80:10509-31.
14. Li P, Li Z, Guo Y, et al. Ag-DNA@ZIF-8 membrane: A proton conductive photoswitch. Applied Materials Today. 2020;20:100761.
15. Pitkanen M. DNA as Topological Quantum Computer. viXra. 2013.
16. Olshansky JH, Zhang J, Krzyaniak MD, et al. Selectively Addressable Photogenerated Spin Qubit Pairs in DNA Hairpins. J Am Chem Soc. 2020; 142:3346-50.
17. Nguyen PTN, Hong NV, Thao PTB, et al. Quantum chemical studies of interactions between Au6 cluster and DNA bases. Science and Technology Development Journal - Natural Sciences. 2020;4.
18. Krenn M, Malik M, Scheidl T, et al. Quantum Communication with Photons. In: Al-Amri MD, El-Gomati M, Zubairy MS, editors. 2016; 455-82.
19. Baldwin GS, Brooks NJ, Robson RE, et al. DNA double helices recognize mutual sequence homology in a protein-free environment. J Phys Chem B. 2008;112:1060-64.
20. Ptashne M. Gene regulation by proteins acting nearby and at a distance. Nature. 1986;322:697-701.
21. Baldwin GS, Brooks NJ, Robson RE, et al. DNA double helices recognize mutual sequence homology in a protein-free environment. 2008;112:1060-64.
22. Holthausen JT, Wyman C, Kanaar R. Regulation of DNA strand exchange in homologous recombination. DNA repair. 2010;9:1264-72.
23. Lai CL, Chen C, Ou SC, et al. Interactions between identical DNA double helices. Phys Rev E. 2020;101:032414.
24. Guguchia Z, Khasanov R, Luetkens H. Unconventional charge order and superconductivity in kagome-lattice systems as seen by muon-spin rotation. npj 2023;8:41.
25. Massachusetts Institute of Technology. 'Kagome metal': Physicists discover new quantum electronic material. 2018.
26. University College Dublin. British Scientists Create First-Ever Room-Temperature Magnetic Monopole. 2010.
27. Ho M-W. Living Rainbow $H_2O$. 2012.
28. Flavin D. The complexity of interactions in transcription and cell replication: biochemistry and physics. J Genet Cell Biol. 2020;3:154-57.
29. Khesbak H, Savchuk O, Tsushima S, et al. The role of water H-bond imbalances in B-DNA substate transitions and peptide recognition revealed by time-resolved FTIR spectroscopy. J Am Chem Soc. 2011; 133:5834-42.
30. McDermott ML, Vanselous H, Corcelli SA, et al. DNA's Chiral Spine of Hydration. ACS Cent Sci. 2017;3:708-14.
31. Abdul Nasir J, Munir A, Ahmad N, et al. Photocatalytic Z-Scheme Overall Water Splitting: Recent Advances in Theory and Experiments. Adv. Mater. 2021;33:2105195.
32. Nasir JA, Hafeez M, Arshad M, et al. Photocatalytic Dehydrogenation of Formic Acid on CdS Nanorods through Ni and Co Redox Mediation under Mild Conditions. ChemSusChem. 2018; 11:2587-92.
33. Klevecz RR, Bolen J, Forrest G, et al. A genomewide oscillation in transcription gates DNA replication and cell cycle. Proc Natl Acad Sci U S A. 2004; 101:1200-05.
34. Mondal PC, Mtangi W, Fontanesi C. Chiro-Spintronics: Spin-Dependent Electrochemistry and Water Splitting Using Chiral Molecular Films. Small Methods. 2018; 2:1700313.
35. Singh H, Ahmed I, Biswas R, et al. Genomic DNA-mediated formation of a porous Cu(2)(OH)PO(4)/Co(3)(PO(4))(2)·8H(2)O rolling pin shape bifunctional electrocatalyst for water splitting reactions. RSC Adv. 2022; 12:3738-44.
36. Singh H, Ahmed I, Biswas R, et al. Genomic DNA-mediated formation of a porous Cu(2)(OH)PO(4)/Co(3)(PO(4))(2)·8H(2)O rolling pin shape bifunctional electrocatalyst for water splitting reactions. RSC Adv. 2022; 12:3738-44.
37. Karthick K, Anantharaj S, Ede SR, et al. Developments in DNA metallization strategies for water splitting electrocatalysis: A review. Adv Colloid Interface Sci. 2020;282:102205.
38. Li X, Dai Y, Ma Y, et al. Landscape of DNA-like inorganic metal free double helical semiconductors and potential applications in photocatalytic water splitting. 2017;5:8484-92.
39. Siebert T, Guchhait B, Liu Y, et al. Anharmonic Backbone Vibrations in Ultrafast Processes at the DNA-Water Interface. J Phys Chem B. 2015; 119:9670-77.

40. McDermott ML, Vanselous H, Corcelli SA, et al. DNA's Chiral Spine of Hydration. ACS Cent Sci. 2017;3:708-14.

41. Alberts B, Johnson A, Lewis J, et al. Molecular Biology of the Cell. 2007.

42. Chou K-C. Low-frequency vibrations of DNA molecules. Bio J. 1984; 221:27-31.

43. Chou K-C. Low-frequency collective motion in biomacromolecules and its biological functions. Bio che.1988;30:3-48.

44. Adey W. Physiological signaling across cell membranes and cooperative influence of extremely-low frequency electromagnetic fields. In: Fröhlich H, editor. Biological Coherence and Response to External Stimuli. New York, NY, USA: Springer; 1988:148-70.

45. Klink OH, W.; Fernandes de Lima, VM. Gravitational Influence on an Oscillating Chemical Reaction. 2011; 23:403-08.

46. Bizzarri MM, N., Minini, M., Pensotti, A. Field-dependent effects in biological systems. Organism Journal of Biological Sciences. 2019; 3:35-42.

47. Harney M, editor. The Effects of Quantum Entanglement on Chromatin and Gene Expression. GeNeDis 2018; 2020. Springer. 2020.

48. Ghasemi F, Tirandaz A. Environment assisted quantum model for studying RNA-DNA-error correlation created due to the base tautomery. Sci Rep. 2023; 13:10788.

49. Siebert R, Ammerpohl O, Rossini M, et al. A quantum physics layer of epigenetics: a hypothesis deduced from charge transfer and chirality-induced spin selectivity of DNA. Cli Epi2023;15:145.

50. D'Acunto M. Quantum Computation by Biological Systems. IEEE. 2023;9:257-62.

51. Goswami PS, Chakraborty T, Chattopadhyay A. A Nature-Inspired DNA Encoding Technique for Quantum Session Key Exchange Protocol. Springer 2022;119-35.

52. Kreinovich V, Urenda JC. Computing Without Computing: DNA Version. 2021;213-30.

53. Alla K, Praneetha, Ramachandran V, editors. A Novel Encryption Using Genetic Algorithms and Quantum Computing with Roulette Wheel Algorithm for Secret Key Generation. Springer. 2020.

54. Raheman F. The Future of Cybersecurity in the Age of Quantum Computers. Fut In. 2022; 14:335.

55. Kasumov AY, Kociak M, Gueron S, et al. Proximity-induced superconductivity in DNA. Science. 2001;291:280-82.

56. Wei Y, Yang Y, Zhang Y, et al. A Frame Theory of Energetic Life: A Twisting Energy Solidified on the Holographic Fractal Structure. App Sci. 2022;12:10930.

57. Flavin D. DNA Transcription regulation by biochemistry and physics: a review. J Genet DNA Res 2018;2.

58. Uchida R. Essential nutrients for plant growth: nutrient functions and deficiency symptoms. Plant nut; 4:31-55.

59. Sanchez DS, Belopolski I, Cochran TA, et al. Topological chiral crystals with helicoid-arc quantum states. Nature 2019; 567:500-05.

60. Olby RC. The path to the double helix: the discovery of DNA. Cou Cor; 1994.

61. Gariaev PP, Marcer PJ, Leonova-Gariaeva KA, et al. DNA as the basis for a quantum biocomputer. DNA Deci J 2011;1:025-46.

62. Zhai J, Cui H, Yang R. DNA-based biosensors. Bio adv 1997;15:43-58.

63. Bockelmann U, Thomen P, Essevaz-Roulet B, et al. Unzipping DNA with optical tweezers: high sequence sensitivity and force flips. Biophy J. 2002;82:1537-53.

64. Meijer DKF, Geesink JH. Phonon Guided Biology. Architecture of Life and Conscious Perception Are Mediated by Toroidal Coupling of Phonon, Photon and Electron Information Fluxes at Discrete Eigenfrequencies. NeuroQuan 2016;14.

65. Mihelic FM. Model of biological quantum logic in DNA. Life 2013;3:474-81. [Google Scholar] [Crossref]

66. Meade TJ, Kayyem JF. Electron Transfer through DNA: Site-Specific Modification of Duplex DNA with Ruthenium Donors and Acceptors. Inte Edi Eng 1995;34:352-54.

67. Patil SR, Mohammad H, Chawda V, et al. Quantum transport in DNA heterostructures: Implications for nanoelectronics. ACS 2021;4:10029-37.

68. Montagnier L, Del Giudice E, Aïssa J, et al. Transduction of DNA information through water and electromagnetic waves. Electromag bio med2015;34:106-12.

69. Fioranelli M, Sepehri A, Flavin D, et al. Quantum information teleportation through biological wires, gravitational micro-bio-holes and holographic micro-bio-systems: A hypothesis. Biochem Biophy Rep 2021;26:101011.

70. Hopkins DS, Pekker D, Goldbart PM, et al. Quantum interference device made by DNA templating of superconducting nanowires. Sci 2005; 308:1762-65.

71. Norman RL, Dunning-Davies J, editors. A Proposed Physical Basis for Quantum Uncertainty Effects. Conf Procee. 2021.

72. Ezziane Z. DNA computing: applications and challenges. Nano 2006;17:27-39.

73. Singh A, Bharadwaj LM, Harpreet S. DNA and quantum-based algorithms for VLSI circuits testing. Nat Com 2005;4:53-72.

74. Irkhin VY, Nikiforov VN. Quantum effects and magnetism in spatially distributed DNA molecules. J Mag Mag Mat 2018;459:345-49.

75. Shasha DL, Cathy. Natural computing: DNA, quantum bits, and the future of smart machines. W.W. Norton; 2010.

76. Minocha S, Namasudra S. Research challenges and future work directions in DNA computing. Adv Comp. 2023;363-87.

77. Cordier BA, Sawaya NPD, Guerreschi GG, et al. Biology and medicine in the landscape of quantum advantages. J R So Inter 2022;19:20220541.

78. Bonde B, Patil P, Choubey B. The Future of Drug Development with Quantum Computing. Springer US; 2024; 153-79.

79. Taniguchi M, Ohshiro T, Tada T. Single-Molecule Identification of Nucleotides Using a Quantum Computer. J Phys Chem B; 2023;127:6636-42.