Quantum Evolution and Genetic Mutations

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Abstract

One of the important problems in quantum biology has been explained in this work. It is the main reason for genetic mutation, which is known as the origin of evolution in organisms. An approach to clarify the main reason for mutation is quantum mechanics. A brief history of genetics, new-Darwinism, and Mendelian inheritance from ancient times to the twentieth century has been presented. The meaning and location of chromosomes and genes in cells, DNA structure, the replication mechanism, the genetic code, tautomeric forms, and the application of quantum mechanics have been described. Finally, we present the importance of quantum tunnelling in playing a main role in the mutation.

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Introduction

We start here by asking these two interesting questions: how do characteristics from one generation pass on to a new one, and how do new characteristics appear in new generations?

The first scientific theory on the subject goes back to Hippocrates. He assumed that the information is collected from man's sperm and woman's menstruation blood. Then this information gets transferred to the uterus. Aristotle opposed and criticised this idea, and he argued that even if a man loses one of his hands, his child will still have both hands. He suggested that there exists an interaction between woman's blood and man's sperm [1].

According to Sanskrit scripture from about 300 BC, the Charaka Samhita argues that a child's characteristics are determined by four factors: those which are transferred by the mother's sexual organs, by the father's sperms, by the

mother's food, and lastly, those characteristics which pass from soul to the child's body. Furthermore, each of these is in turn composed of four parts, and the overall sixteen factors will contribute to determining a child's characteristics [2].

The notion of heredity changed profoundly during the nineteenth century. In 1866, Charles Darwin suggested Pangenesis as a hypothetical mechanism to describe heredity. According to this theory, each cell in an organism emits organic particles which are called gemmules. They circulate in the body and are finally collected in the gonads. The particles transfer characteristics to the next generation. Experiments in the nineteenth century did not show any evidence of these particles. But recent experiments show that nucleic acid and the prions perform the same role [3].

The most interesting and important work on heredity was carried out by Gregor Mendel and published in 1865. The work was neglected by the scientific community until 1901 when Hugo de Vries brought Mendel's work to life. Mendel discovered the mechanism of heredity through experimentation on peas. He considered seven properties of the peas. Mendel observed that the re-appearance of the properties is controlled by certain factors which nowadays we call genes. He saw that in the first generation, some properties would not show up. He divided the properties into two and called them recessive and dominant [4].

In this work, we describe DNA and the transfer of heredity information to the next generation, and finally, we explain the role of quantum mechanics in all of this.

Chromosomes and the DNA Structure

One of the most important discoveries at the end of the nineteenth century was the chromosome. The chromosomes in cells can be seen with a normal microscope. They consist of hereditary genes called Deoxyribonucleic acid or DNA, which carries hereditary commands. The main role of DNA is to save genetic information. Deoxyribonucleic acid has a complex composition and a high molecular weight which plays a role in protein construction. The genes are units of heredity that determine the properties of an organism. Genes hold information about protein structure and are saved in DNA sequences, while in some viruses, they are saved in RNA. For a genetic property to show up, the gene must translate the information into a protein. Various proteins are activated in a cell as a result of different genes' activities. All saved genetic information is called the genome [5] (Figure 1).

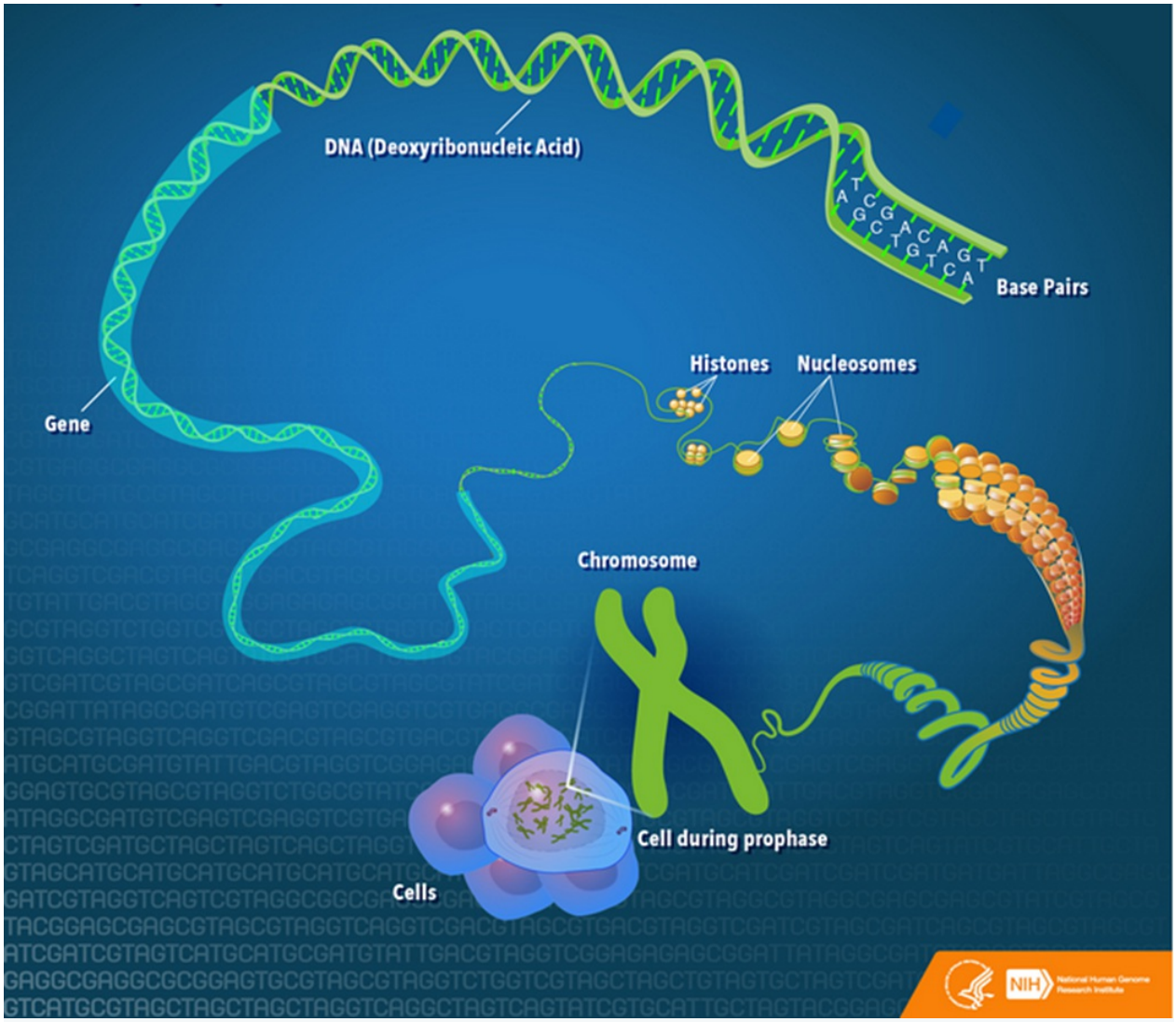

Figure 1. Location of genes and chromosomes in a cell/Source: National Genome Institute

The number of chromosomes in a human cell is 46 (2x23), and the number of genes is approximately 19,000-20,000. Sometimes DNA is called a map, as it holds all the commands that are necessary to make all parts of a cell, including proteins and RNA. Some parts of DNA are the bases for genes, while other parts of DNA build structures or make arrangements of information. A chimerical view of DNA is a long polymer with some basic blocks as nucleotides. The strands that hold everything together consist of sugar and phosphate groups that are connected via ester linkages (organic acids that make up a composition as esters, having a general formula of R-CO-OH). As we mentioned, DNA exists inside each cell's nucleus. It consists of two strands of sugar and phosphate and a pair of bases, thymine (T), adenine (A), guanine (G), and cytosine (C). Together, sugar, phosphate, and a base form a nucleotide. All the information about a cell's activities has been encoded via the arrangement of the four nucleotides. The nucleotides consist of deoxyribose sugar, a phosphate group, and one of the four bases that we mentioned above, which are nitrogen bases. The molecule is like a curled ladder named the double helix. The ladder part of the molecule, composed of sugar-phosphate molecules and their neighbor nucleotides, holds covalent interactions, and there is a hydrogen connection between the phosphates that form the curled DNA strand. Nitrogen bases are tied together. Both nucleotides hold a

hydrogen link, and they are DNA units. In a DNA molecule, adenine is always connected to thymine (A-T), while cytosine is connected to guanine (C-G)[6].

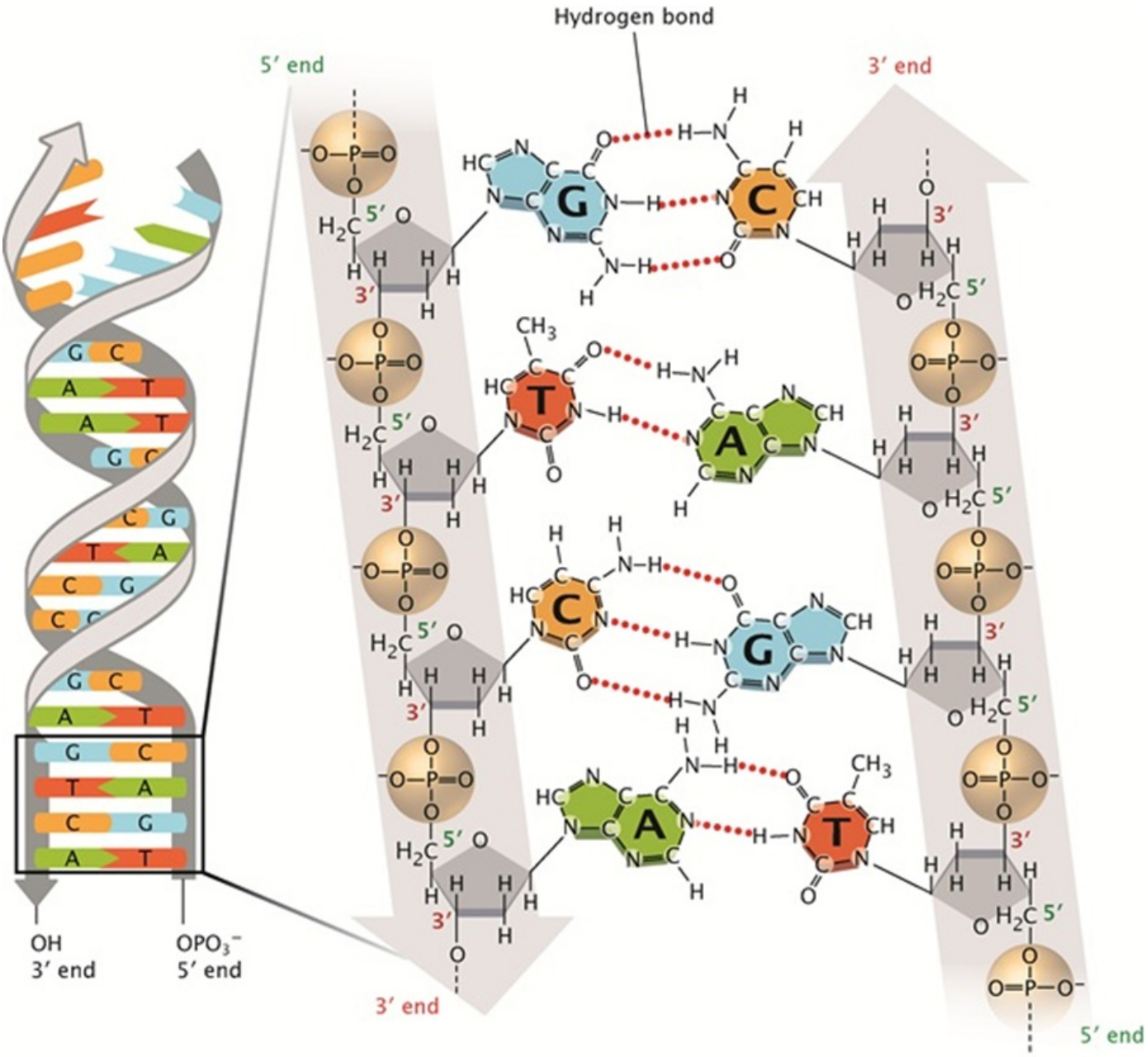

Figure 2. The DNA Structure[6]

The main question in any evolutionary process is what causes or initiates a change. How have changes in a species happened and been saved? At the beginning of the twentieth century, a Danish botanist by the name of Hugo de Vries invented the word “gene” to distinguish an individual’s phenotype from its genotype.

He observed in a potato farm a completely new type of Oenothera lamarckiana which was longer than the normal ones and whose petals were oval-shaped rather than the normal heart-shaped ones. He understood the flower should be a mutant, and he showed that the mutant characteristics transferred to the next generation [7].

T. H. Morgan from Columbia University studied Hugo De Vries's mutants. He used the fruit fly as his subject. He exposed them to intense X-rays, used strong acid on them, and gave them poison. It was only in 1909 that he managed to find fruit flies with blue eyes [8].

This approach is known as the Mendelian approach. A combination of this approach with natural selection is also known as Neo-Darwinism, whereby a mutation is caused by a change in the genetics of the parent cell. This process produces, provided that natural selection supports it, a more adaptable new species. If, on the other hand, natural selection is not in favour of the new change, then the new species is discarded. The successful mutations will be saved for the next generations to come, and evolution carries on.

In Neo-Darwinism, the mutation occurs completely at random, i.e., the changes do not occur in response to just one environmental variation. While the environment keeps on changing, it will require a very long stretch of time for an adaptable mutation to happen and persist. This approach is in sharp contrast to the Lamarckian approach of evolution, whereby mutation occurs as a consequence of an environmental challenge and is saved, similar to that of giraffe neck lengthening. The theory of natural selection was discarded then, but it regains its importance nowadays [9].

The main question in the last century was how the mutations during cell division occur and what the mechanism behind them is. To answer these questions, it is necessary to explain the most important part of cell division: DNA replication. This process holds the hereditary characteristics of the cell. The DNA structure allows for the contributing enzymes and proteins to be in a loop. Each strand of the double helix is the reverse of the other, which means that the end of one is the start of the other. The replication stages can be summarised as follows: an enzyme such as DNA gyrase makes an opening in the double helix, then another enzyme, such as helicase, separates the two strands. To maintain this separation, a huge number of tiny proteins, like SSB, attach themselves to the DNA fibres. The DNA polymerase enzyme joins a base to T and a C base to G along the DNA fibre and then checks the entire process. At the end, there should be two double helixes. Of course, if the process of DNA replication goes perfectly well, the new generation will be an exact copy of the old one. But in reality, errors can and will occur in the above process, and hence there will be variations in different generations. In humans, there are approximately 86 new mutations across a 6 billion genome area [10].

Tautomerization Process

Watson and Crick, the founders of DNA, suggested in 1953 that a process such as tautomerization is the cause of mutations, which is basically the motion of protons inside a molecule (tautomers are typical isomeric compositions with the same molecular formula, but their connected mutual bonds group to the circle between inside and outside the circle can change) [11]. Every physicist knows that any process that deals with the motion of protons is a quantum mechanical one. Schrödinger, in his book "What is Life," published in 1943, mentioned that mutation should fall in the quantum mechanical realm. Was Schrödinger correct?

In Figure 5, the hydrogen bonds are shown as dashed lines between oxygen and nitrogen. This implies that there is a shared proton. A proton is a quantum entity holding simultaneously both particle and wave properties. According to

quantum mechanics, the position of the proton cannot be known exactly. It moves between two bases. The position of the proton (H) is not exactly in the middle of the two bases, but it is closer to one of them. This asymmetry is necessary for an important feature of DNA replication.

Consider a pair (e.g., A-T), where A is on one strand and T is on the other, and together they hold the two hydrogen bonds (protons), where one of the protons is nearer to the nitrogen atom and the other near the oxygen atom in T (Figure 5a). It opens a possibility to make a hydrogen bond at A-T. However, there is a set of possibilities to find the particles in many places. If the two protons that they hold (genetic letters) jump to the other side of the hydrogen bond, then this means that they become close to the other bases (Figure 3) [12].

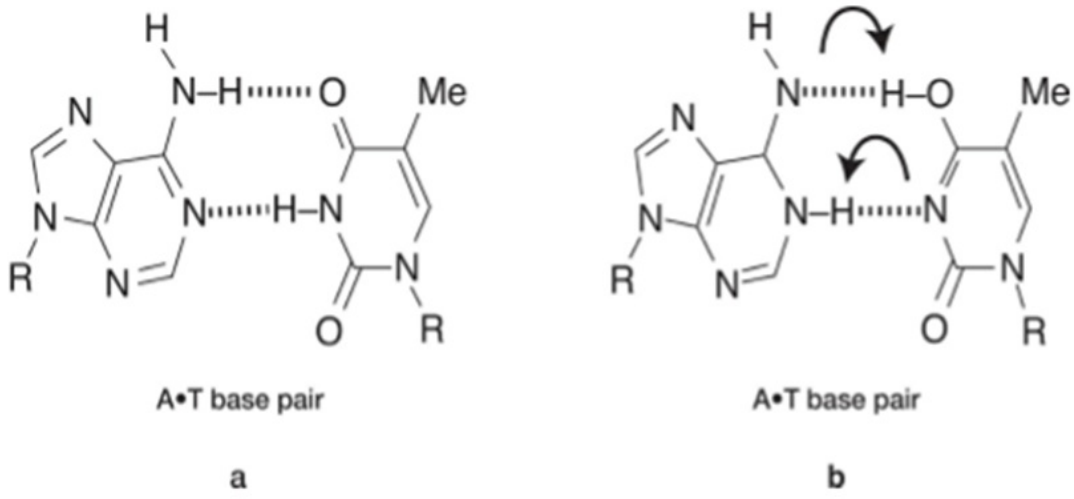

Figure 3. (a) Standard double bases of A-T with their protons in normal positions. (b) The double protons make a mutation in the cross of the double helix to produce a tautomeric form of both A and T [12], p. 223.

We know that the protons, which make hydrogen bonds in the DNA, are responsible for determining the double bases that are used in genetic code replication. So if encoded double protons move (in the opposite direction), they will write the genetic code effectively. If, for example, a genetic letter on a DNA strand is T, which is normally connected to A, now, through exchanging the protons, both A and T accept a tautomeric form. Of course, it is possible that the protons jump back again. However, if this were to happen, then they will be in a rare tautomeric form. The tautomeric forms of guanine and thymine are known as enol or keto depending on the position of the encoded protons, while the tautomeric forms of cytosine and adenine are known as the amino form. At the time of copying DNA strands, it is possible that errors may occur in connected bases to the strands. In a tautomeric form, T may connect to G instead of A. Consequently, G will contribute to the new strand, while A will be left behind in the old strand. Similarly, during DNA replication, if A is in a tautomeric form, instead of T connecting to C, then this will lead to leaving behind a T on the old strand (Figure 4). In these cases, the DNA strands carry mutations, which means that changes in the DNA will be transferred through generations.

Of course, it is not easy to provide direct evidence for the above assumption. However, in 2011, a research group at Duke University tried to clear that mistake of coupled bases in DNA with protons in tautomeric form. Actually, it can stay on in the DNA polymerase places. Therefore, it is possible to suddenly change to a new DNA that exhibits mutation.

However, it appears that tautomers are the cause of mutations, and evolution proceeds in this way. But the question is, why do the protons move toward the wrong positions? Few classical solutions state that the reason goes back to the molecular vibrations caused by external factors.

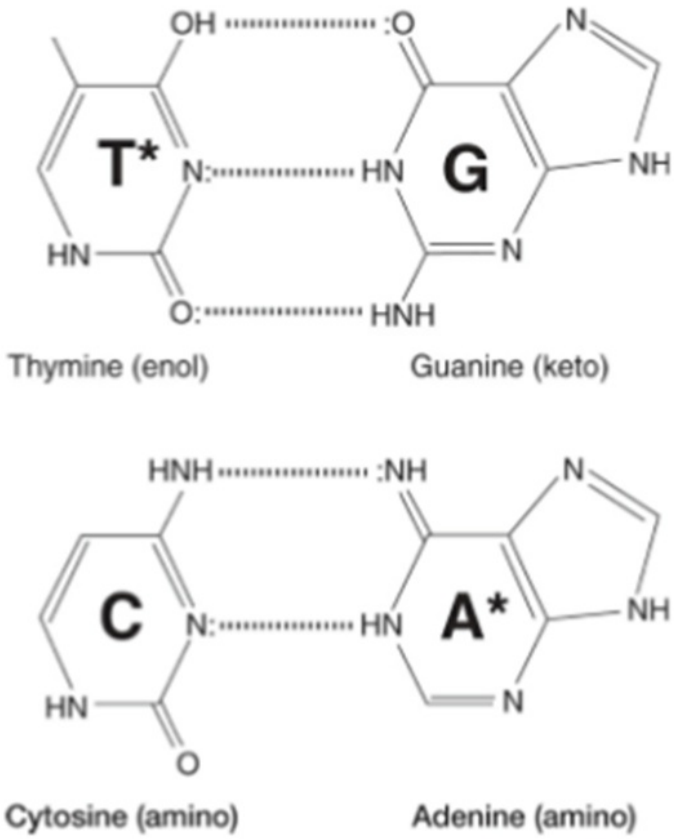

Figure 4. In the tautomeric form (enol), shown as T*, T wrongly connects to G instead of A. Similarly, A can make a mistake and connect to C. If these errors happen during DNA replication, then mutations will occur [12], p225.

Entering Quantum Mechanics

The protons must overcome the energy barriers to start their motion. Alternatively, the protons may be pushed by the nearest water molecule, and there are just a few number of these molecules nearby. Another way to achieve the same is quantum tunnelling. It is a phenomenon that allows particles to appear or exist in classically forbidden locations. Quantum tunnelling can pave the way for the protons to overcome hydrogen bonds to create tautomeric forms [5].

DNA mutations can be formed by different mechanisms, for instance, chemical destruction, ultraviolet rays, radioactive decay, and cosmic rays. All these mechanisms are based on the molecular level, which truly can be regarded as a

quantum mechanical process. Although there is not strong evidence yet in favour of quantum tunnelling, if it plays a role in the basic tautomeric forms of DNA, then quantum mechanics will have a vital role in mutations that produce further mutations.

According to McFadden and Al-Khalili [12], the basic tautomeric forms of DNA provide approximately 0.01% of all natural basic DNA, which is able to make the same ratio of errors, namely, much less than 1 in a billion. These ratios are about the same ratio of mutations in nature. Therefore, if the basic tautomers are in a double helix shape, then many errors will be corrected, which keeps high fidelity in DNA replication. There are errors originating from quantum tunnelling that are not detected by various correction engines. These errors may be regarded as those that are behind the evolution of the origin of life on Earth.

The problem with tunnelling, as a cause of mutation, is that it cannot easily be turned off or on. This is in sharp contrast to other well-known causes such as chemical mutagens and radiation. Therefore, it is not easy to measure mutation rates with and without tunnelling to see the difference. In recent years, research done by A. D. Godbeer, J. S. Al-Khalili, and P. D. Stevenson shows that quantum tunnelling may not be a significant mechanism for the creation of adenine–thymine tautomers within DNA, even with coupling to a thermal medium[13].

There may be a way to show that quantum mechanics is a cause of mutation. This can be done by comparing classical and quantum information. Classical information can be read many times without changing it, while quantum information changes each time by measurement. Hence, when the DNA polymerase enzyme breaks a DNA strand to find the position of a codon proton, it actually performs a quantum measurement. If the proton state corresponds to a genetic code letter, then the measurement can be regarded as a cause of mutation.

Although all of the genome of the cell is copied at the time of DNA replication, most of the reading of the genes doesn’t occur at the time of DNA replication; it occurs at the time of the process wherein genetic information is applied for protein synthesis. The process divides into two parts: transcription and translation. The copying of information from DNA to RNA and from RNA to protein machinery synthesizes. In the process, it is possible that one gene more than others is read. If the reading of the DNA code during transcription is via quantum measurement, then we should expect the deformation of a gene to be possible. Of course, that increases the probability of mutation. Studies on human genes show that genes that are read in a high state more readily accept mutation. Although the evidences are consistent with quantum measurement, they do not prove they hold quantum mechanics.

Reading of DNA holds chemical interactions that can, via various ways, destroy molecular structures and cause mutations without necessarily invoking quantum mechanics. Yet in biology, we need certain evidences of quantum mechanics' role.

Conclusions

As we mentioned above, so much work has been done on genetic changing mechanisms and the reasons behind mutations in different generations. But yet there is not a confident explanation to address the burning issue of how errors

creep in the process of copying genetic codes. Quantum mechanics is an effective and important instrument that could provide a correct explanation for the mutation problem. Quantum tunnelling is our first choice for such a mechanism, but no one is sure. Although there are many theoretical reasons to support it, experimentally it is not easy to control and observe a quantum tunnelling process in a DNA environment. We believe that more research is needed to clarify the quantum mechanical role in mutation. Schrödinger, as we alluded to earlier, was the first scientist to say that quantum has a role in mutation, but as yet, we are not sure.

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