A Zometool Model of the B-DNA

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Abstract

Different activities in the fields of scientific research and education gave the idea to create a Zometool model of DNA. The geometric model of the molecule was restricted by symmetry properties of the modeling tool and some practical demands. The result shows similarities to an architectural construction, notably to the dual spiral staircase.

Introduction

Teaching different subjects for architecture students, especially descriptive geometry and computer aided design, as well as scientific research of connections between art and geometry determined the topic of workshops for students and talented children. These activities and the incentive got at a conference on symmetry gave the idea to construct a Zometool model of DNA. The geometric modeling of the molecule was restricted by symmetry properties of the modeling tool and some practical demands. It has to stand alone, require less types of elements and the structure could be separated to repeatable parts, easy to build even by children.
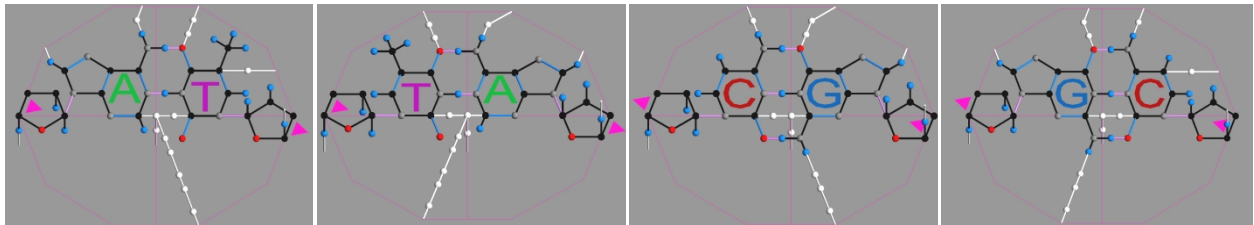
The first structural sketch was built at an international summer school for architect students in Rijeka, Croatia. Another experimental modeling was built with the help of foreign and Hungarian students and pupils at different educational events and in workshops for talented children. The first public introduction took part at the Symmetry Festival in Delft, Netherlands. The highest model was built for the first time at the nation-wide Researchers' Night in Pécs, Hungary (Figure 9). The next event was the national student conference on biology, organized at the University of Pécs (Figure 10).

The Structure of the Model

Helical surfaces are created by a straight line rotated around an axis and moved along this with constant speed. If the line intersect the axis in right angle, the surface follows the structure of spiral staircases. The construction of the model was supported by the similarity to the doubled ones. A left-handed example can be seen in the royal castle in Chambord, France, possibly designed by Leonardo da Vinci [4].

The B-DNA is the most common form of DNA molecules. Its structure has two important parameters. The height of the approximately whole turn of the right-handed helix pair consists of ten nucleotide pairs. In this molecule the planes of the base pairs are almost perpendicular to the axis of the helices. Thus the geometrical layout of the model follows the planes of a right decagonal prism. One of the four nucleo-bases (Adenine, Thymine, Cytosine and Guanine) with a 5-carbon sugar, a deoxyribose molecule, is a nucleoside. Together with phosphate molecules, these give the nucleotides. Figures 1−4 show the modeled nucleoside pairs. The phosphate molecule has to be modeled in two different forms, depicted in

Figure 5, because of the symmetry properties of Zometool. The different atoms and different types of chemical bonds are marked with different colors. The elements of the supporting structure are white-colored. The planes of the sugar molecules are rotated into the planes of the base pairs in the model. This makes it possible to avoid too many types of struts, and the construction can be followed easier. The static features are also more favorable regarding the stiffness and deflections. The model requires only three different types of struts. Two of them with rectangular cross-section have two different lengths, the third one with pentagonal cross-section has the same length. Figure 6 shows a possible initial nucleotide pair with the stiffening base dial.

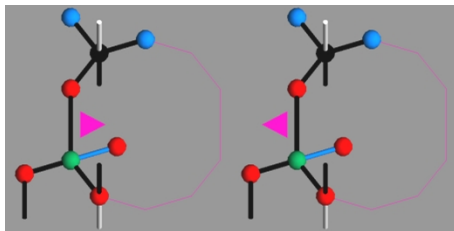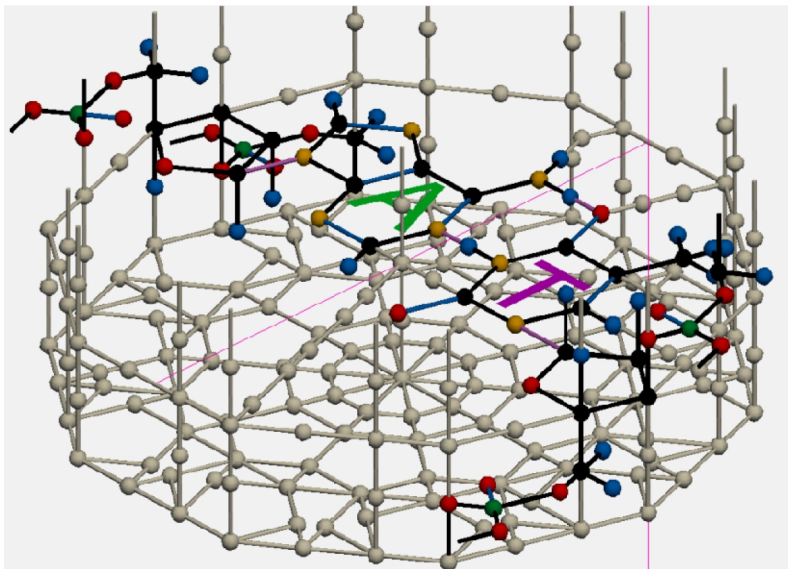**Figures 1−4**: *Modeled nucleoside pairs of the idealized B-DNA molecule*

Fig. 5: *Modeled phosphate molecules. The lateral surfaces of the struts are differently sloped (pink narrows).*

Figure 6: *A possible initial nucleotide pair with the stiffening base dial. The supporting spatial grid is white and the beginning zero level of the helical structure is signified with a decagonal strand.*

The node element of Zometool makes it possible to follow tenfold rotational symmetry in the median plane but the neighbor struts of a decagon slope inwards and outwards respectively (pink narrows in the Figures 1−5). Four nucleobase pairs occur in the DNA. A-T and T-A as well as C-G and G-C seem to be mirrored pairs but, together with the sugar molecules, the geometrical operation is, instead, a rotation of 180 degrees. This way the symmetry of the sugar molecules can be maintained, since these occur only in right-handed natural form. The related nucleoside pairs could be derived from each other by rotation as depicted in Figure 7, using axis **b**. The same operation would be also applicable around axis **c** with the phosphate molecules. However the modeled pairs have different forms according to the above-described differently sloped struts. The other necessary change can be seen in Figure 8. The outer side of the sugar molecule must be parallel with the next edge of the decagon and the modeled phosphate molecule has to be shifted in the signed direction. This way the helices can intersect opposite edges of the prism, keeping the rotational symmetry. The water drop shaped signs are the same in the next figures. These are moved together with the considered model parts, so the black and gray colored symmetric surfaces follow the described spatial transformations.
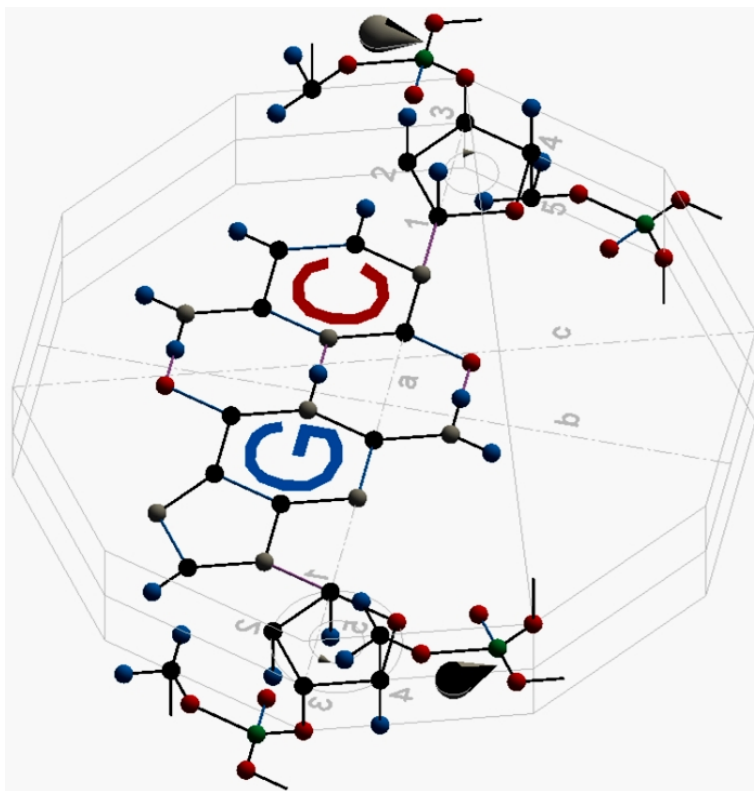
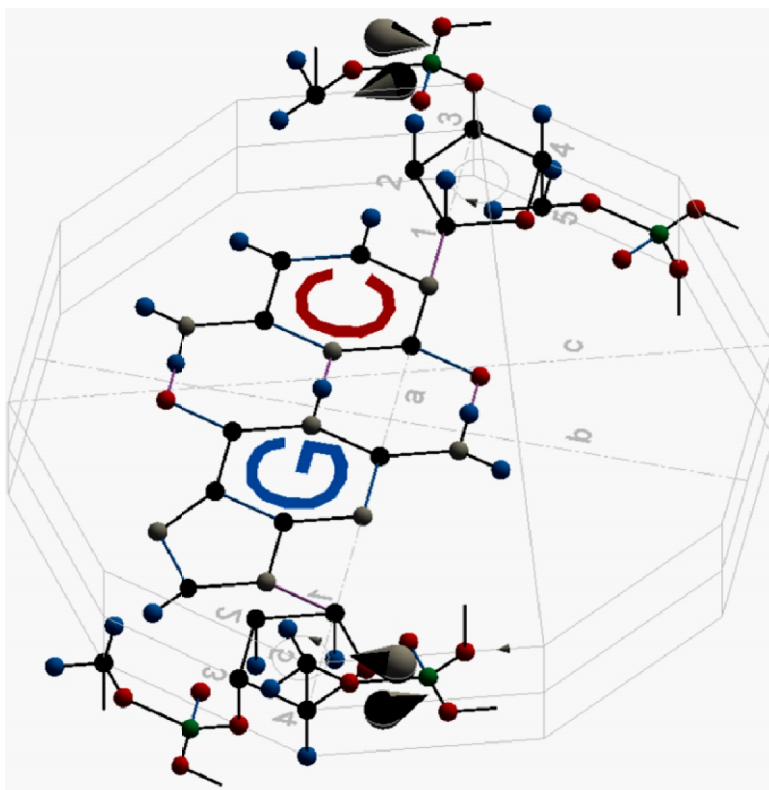**Figure 7**: *The primary symmetry properties of a nucleotide pair in the model*

Fig. 8: *The modified level of a nucleotide pair due to the tenfold rotational arrangement of the model*

Figure 7 shows the directions of sequences between the so-called 3' and 5' ends related to the numbering of carbon atoms joining the phosphate molecules. Notice that the helical strands are anti-parallel. The signs rotated 180 degrees around the vertical central axis also show the movement according to a paired spiral staircase interpreted upside-down (Figure 8). The highest built model, more than 5 meters in height, with one and two turns can be seen in Figures 9 and 10.

| Figure 9: *Half-time of the modeling at the nation-wide Researchers' Night in Pécs, Hungary.* | Fig. 10: *Last steps at a Hungarian student conference on biology* |

Acknowledgment

References

[1] *Az élet molekulái (Molecules of the Life),* Tudomány, December, 1985/4 (Issue of the Hungarian edition of Scientific American)

[2] L. Pray, *Discovery of DNA structure and function: Watson and Crick,* Nature Education, 2008 http://www.nature.com/scitable/topicpage/discovery-of-dna-structure-and-function-watson-397

[3] Wikipedia, *DNA,* https://en.wikipedia.org/wiki/DNA

[4] Helac, *Escalier Chambord.jpg*, https://commons.wikimedia.org/wiki/File:Escalier_Chambord.jpg