The Modular Construction of DNA Double Helix

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In the annals of science, rarely if ever, has any molecule captured the imagination of mankind as DNA. Within five decades of the discovery, DNA structure has been able to disseminate knowledge of key aspects related to life. From grade levels to research studies, DNA is described, examined and analyzed from diverse vantages that extend from the simple double helix to the correlation of this structure with hundreds of properties that ensue from this unique arrangement. The overt structure of the DNA double helix is very deceptive. Although constructed from fewer modular blocks compared to proteins and enzymes, this simplification has been more than compensated by the exceptional versatility of the DNA double helix. Thus, varied functions such as replication, transcription, recognition and intercalation – each describing a different pathway – are possible because of its magical flexibility. DNA is a maverick and a good host; its usual right-handed helix profile can change all the way to the left-handed double one, the entire spectrum with expenditure of minimum energy. Its major groove can play host to countless guests leading to recognition and the resulting biological functions; its minor groove can receive antibiotics initiating a cascade that protects our lives from microbial invasion; its horizontal gap is a beacon for suitable guests to snugly fit in and thereby initiate many critical operations.

Our continued interest in the modular assembly to structures, made it logical to design one for the DNA double helix. The outcome, although appears very simple, took a long time. The design presented here can be assembled even by students at the grade levels. Yet, it encompasses the key structural aspects of DNA duplex, such as the pitch, major groove, minor groove and the helicity and, in addition is so versatile that it presents the DNA single strand complexed with complementary bases, the


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Modular construction, DNA, double helix.

Respectfully dedicated to Darshan Ranganathan, who passed away on her sixtieth birthday.

tethering of which can either give rise to the normal right-handed double helix, B-DNA or the left-handed double helix, Z- DNA.

Construction of the Module

Materials:

Card sheet of ~1mm thickness; scale; cutter/scissors; Fevicol.

Procedure:

A. The module

1. Cut out rectangle of size, 20 cm × 2 cm; holding firmly by the scale, make vertical lines at intervals, 2 cm, 4 cm, 6 cm, 14 cm, 16 cm and 18 cm – to produce segments, *a, b, c, d* and *c', b', a'*. Crease the lines, using the scale, by folding inwards and outwards (1, *Figure* 1).

2. Holding the *d* segment vertically, fold back *c*, fold to the front *b* and *a*. This procedure would place segment *a*, overlapping with *d*. Glue securely *a* with portion of *d* (2, *Figure* 1). Repeat the same procedure with, *c', b', a'* (3, *Figure* 1).

3. Fold flaps *b, c* and *c', b'* to the middle (4, *Figure* 1). Crease firmly by moving the edge segment forwards and backwards. Now each flap will have four 1 cm wide strips. Gently open the two flaps on either side of *d*(5, *Figure* 1). Bring the *b, c* and *c', b'* edges to the two edges of *d* to form the module (6, *Figure* 1). The two sleeves (*b, c* and *c', b'*) that sandwich segment *d* and placed orthogonal, could represent the sugar phosphate backbone of DNA and segment *d*, a hydrogen bonded pair of code bases. It is clear that tethering of the sleeves; equivalent to the operation of enzyme DNA polymerase, will generate the double helix.

4. 15-20 modules are needed to assemble a DNA that would clearly show all the features (the pitch, the turn, major and minor grooves). In the beginning it is better if they are made individually. The required 15-20 rectangles can be cut out from sheets of size, 20 × 30, 20 × 40 respectively. In principle, the

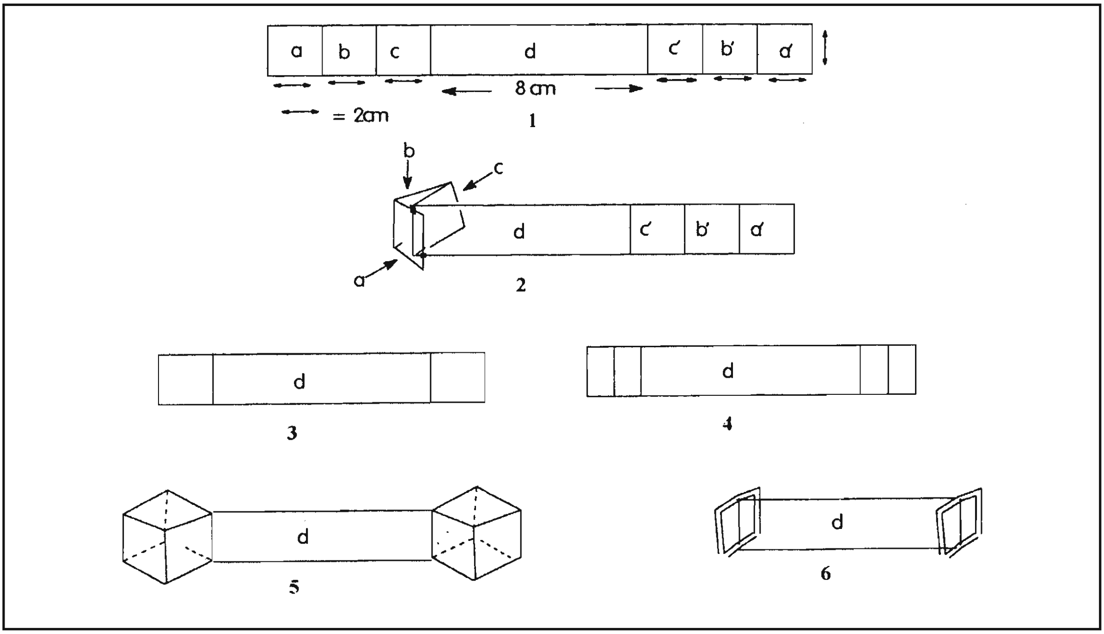

Figure 1.

segment could be inscribed in the sheet, prior to their separation, to give not the rectangles, but the modules themselves. Because of alignment problems, unless great care is taken, the modules do not come uniform in this approach.

B. Tethering

1. Make the two tethering strands by cutting out rectangles from paper board of the same thickness. Their width should be > 2 cm this is because the inner side of sleeves made from 2 cm segments would be slightly less than this, ~1.8cm). The length of the rectangle can be derived from the formula, $2n+5$ cm, where n represents the number of modules to be tethered. Thus for a 20 module duplex, the strand should be of dimensions, 45 cm × 1.8 cm. Make one side of the strand pointed by cutting out triangles from the sides (7, *Figure* 2)

2. Each module, although symmetric, would have two sides, the plane one and the pasted one. For aesthetic reasons only, string the modules on one of the two strands, all facing the pasted side (8, *Figure* 2). Structure 8 models the two important functions of

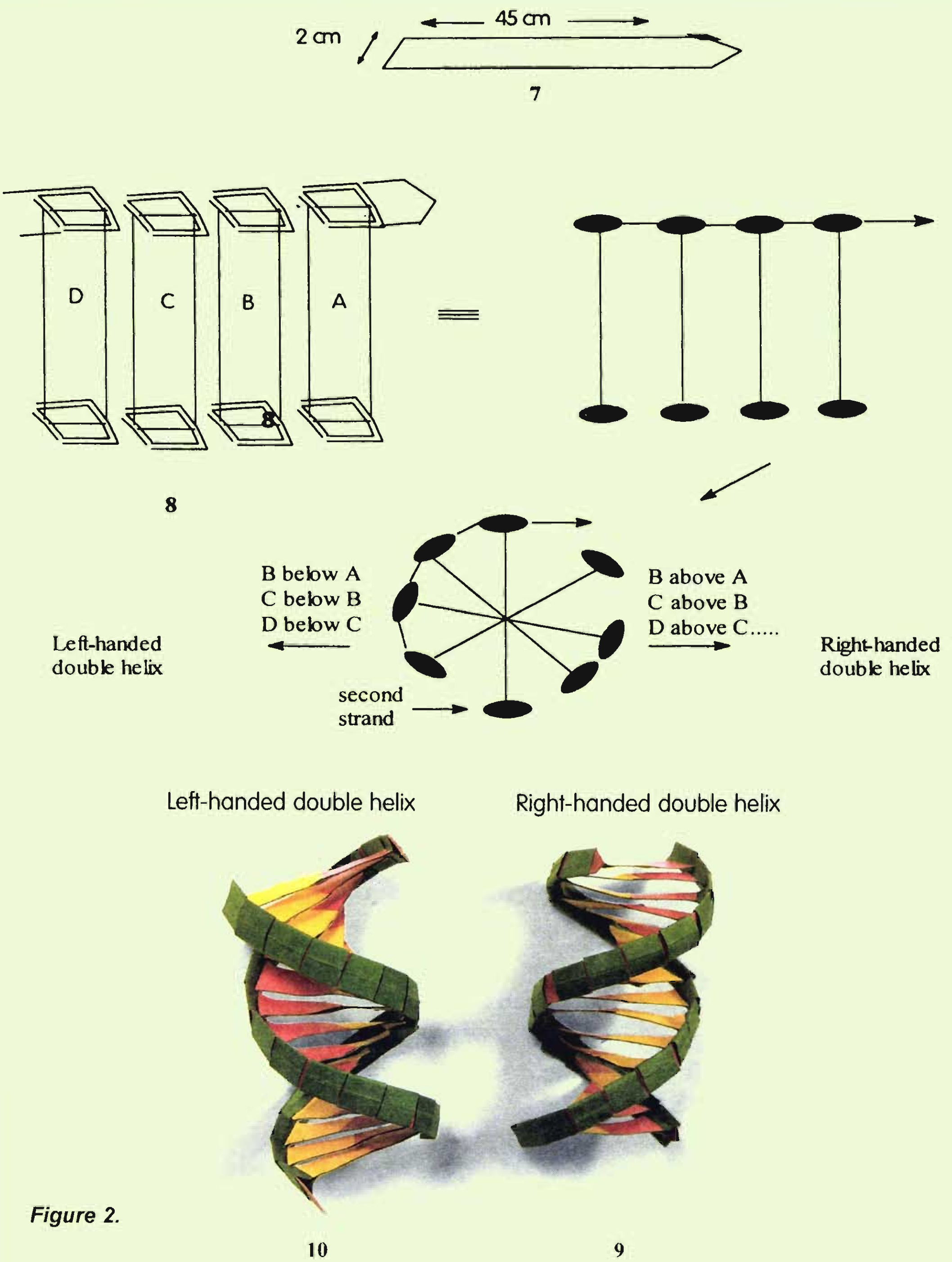
2 cm
45 cm
7
D
C
B
A
8
≡
8
B below A
C below B
D below C
Left-handed
double helix
B above A
C above B
D above C.....
Right-handed
double helix
second
strand
Left-handed double helix
Right-handed double helix
10
9

Figure 2.

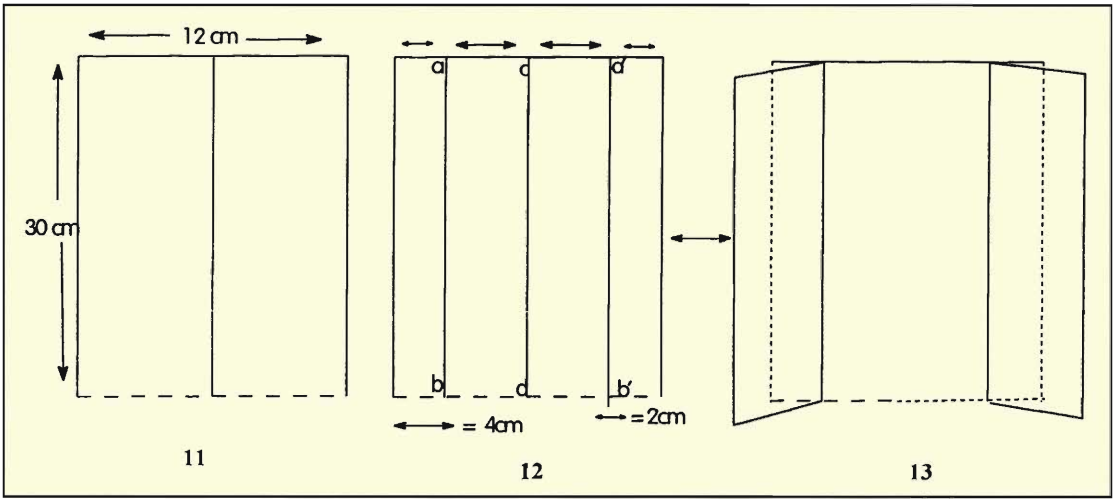

Figure 3.

DNA, namely, replication and transcription. In the former case, 8 would represent a DNA single strand-generated by splitting of the mother duplex – where complementary DNA nucleotides (A, T, G, C; A = adenine, T = thymine, G = guanine , C = cytosine) are lined up for tethering to generate the daughter DNA duplex. In the case of replication, 8 would represent a DNA single strand where complementary RNA nucleotides (A, U, G, C; A = adenine, U = uracil, G = guanine, C = cytosine) are lined up for tethering to generate a single stranded *m*-RNA that can translate the message in the duplex to functional systems like enzymes, proteins and hormones.

3. Structure 8 is devoid of asymmetry needed for DNA. This key feature is to be introduced in the tethering with the second strand, to generate either a right-handed double helix or a left-handed double helix.

4. ***The right-handed double helix (9):*** Using the second strand, tether the modules such that each succeeding module is *above* the preceding one. Thus if the modules are A, B, C, D..., tether B *above* A, C *above* B, D *above* C, etc. This will automatically produce a right-handed double helix, B-DNA (9, *Figure* 2). Stretch the strand till the right pitch is secured (~10-11 bases per full 360° turn of any one strand). Note the major groove, the minor groove and sites for intercalation.

5. ***The left-handed double helix (10):*** Tether the modules by stringing each succeeding module *below* the preceding one. Thus if the modules are A, B, C, D... tether *B below* A, C *below* B, D *below* C, etc. This will automatically produce a left-handed double helix, B-DNA (10, *Figure* 2). The operation is exactly the mirror image of the earlier one! Stretch the strand till the right pitch is secured (~ 10-11 bases per full 360° turn of any one strand).

C. DNA Double helix from strips

Material: Stout envelope of ~1 mm thickness and size 12 cm × ~30 cm (11, *Figure* 3).

1.. Holding firmly by the scale, fold 2 cm from the edges along a,b and a', b' (12, *Figure* 3). Gently open the seam of the envelope along c, d. Pull back along a, a' and b, b' (13, *Figure* 3), apply a layer of glue and fold back securely to the original position 12. Make 2 cm strips from 13 to give motif 3 (*Figure* 1). Proceed from here, precisely as shown in *Figure* 1.

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Suggested Reading

[1] **S Ranganathan, Molecular Origami: Modular construction of platonic solids as models for reversible assemblies, *Resonance*, Vol. 5, No. 9, p. 82, 2000.**

Chemistry has invaded our lives, has provided with new foods and new materials, has replaced wood and metal with less expensive products, has enabled low-income classes to acquire things that otherwise would have been inaccessible.

Luciano Caglioti
The Two Faces of Chemistry