DNA Structure and Replication Molecular Model Activity

Student Study and Analysis Sheet

Introduction

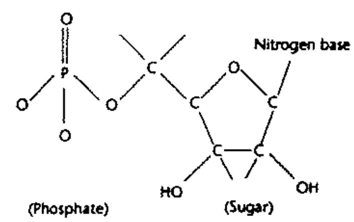


Figure 1
A nucleotide

Deoxyribonucleic acid, DNA, is responsible for storing information concerning the structure of proteins and the genetic profile of an organism. In order to pass this information along to future generations of the organism, the DNA must be perfectly replicated in both amount and content. If the nucleic acid were not reproduced to such an efficient degree, characteristics of heredity would be disrupted, and an organism's identity would be devastated.

Only five elements are involved in the formation of a nucleic acid: carbon, hydrogen, oxygen, nitrogen, and phosphorus. They combine in three distinct subunits to form a nucleotide [Figure 1], the smallest piece of a nucleic acid strand. The first subunit is one of two sugars. Ribose is a five carbon sugar with hydroxyl (-OH) functional groups extending from the first, second, third, and fifth carbon. Ribose is only found in ribonucleic acids (RNA). If the hydroxyl group is absent from the second carbon, the ribose is said to be deoxyfied (oxygen removed), and the sugar is now called deoxyribose. Deoxyribose is only found in deoxyribonucleic acids (DNA).

The second subunit is a phosphate radical group. Derived from phosphoric acid, a phosphate contains a centralized phosphorus atom surrounded by four oxygen atoms. The phosphate bonds with the sugar in an alternating pattern. Two of these sugar-phosphate strands make up a DNA molecule, and the strands run parallel to each other like railroad tracks.

These "tracks" are linked at every sugar section by the third subunit, called a nitrogen base. Only four possible bases exist for DNA. Cytosine and thymine are the two possibilities which have smaller, single-ring structures (categorized as pyrimidines), while adenine and guanine are the larger, double-ring structures (categorized as purines). RNA contains the same possible bases as DNA, with the exception of thymine, which is replaced by the base uracil. When two nucleotides join at their nitrogen bases, they do so in a specific manner. Because of the constrictions on hydrogen bonding, cytosine can only partner with guanine, and thymine only with adenine. When the single strands of DNA are hydrogen bonded, the finished molecule takes on the shape of a double helix [Figure 2]. This resembles a ladder that has been twisted into a spiral staircase structure. Before a cell can divide, its DNA must be replicated. The process by which DNA in chromosomes is copied before cell division is called replication. During replication, the hydrogen bonded nitrogen bases in the DNA double helix molecule split. The molecule appears to unzip at this section. An enzyme called DNA polymerase moves along the unzipped strands and adds the correct complementary nucleotide to the strand. Complementary nucleotides bond to each side of the unzipped DNA, forming two new DNA strands which are identical to the original. Since the single strands which make up the DNA are mirror images, both can be used to rebuild the opposing single strand. This allows for the exactness in replication.

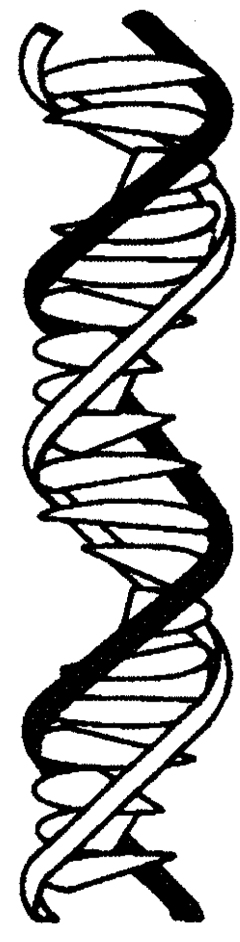


Figure 2
The DNA double helix

Objective

Models will be used to visualize the double helix structure of DNA. They will emphasize the hydrogen bonding which connects nitrogen base subunits, and how those bonds break and reform to replicate the DNA strand.

Materials needed per group:

1 DNA Replication Model Packet, containing:
- 16 black, deoxyribose molecule pieces
- 14 white, phosphate molecule tubes
- 4 red, guanine base tubes
- 4 blue, thymine base tubes
- 4 green, adenine base tubes
- 4 black, cytosine base tubes
- 8 hydrogen bonding plugs

1 Student Study and Analysis Sheet (per student)

Procedure

Part I - Building a DNA molecule

1. Laying down the track

A. Obtain seven phosphate model tubes and eight deoxyribose sugar molecule pieces. Connect these in a straight chain, so that the third, open bonding site on each sugar is facing the same direction. Obtain seven more phosphate tubes with eight sugar pieces, and form a second chain with each extra bonding site facing the same direction. Set the chains parallel to each other on the table so the empty bonding sites face each other and form a structure that resembles railroad tracks [Figure 3].

B. Phosphate and sugar alternately bond to form the backbone of all DNA molecules.

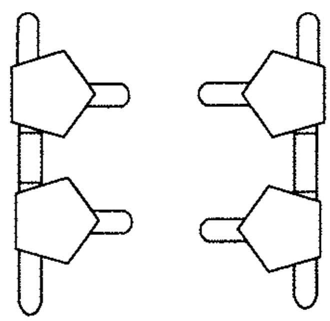


Figure 3
Phosphate-sugar chains

2. Making the rungs

A. The open bonding site on each nucleotide's sugar is filled by a nitrogen base. DNA has four possible nitrogen bases, and they have been color coded for this investigation (see the materials list at the beginning of the study and analysis sheet). Starting at the top of one of your phosphate-sugar tracks, bond the following nitrogen bases, in order, to the strand: guanine, cytosine, adenine, thymine, thymine, guanine, adenine, and cytosine.

B. The second chain of phosphate-sugar molecules also contains nitrogen bases, and they are aligned in a specific arrangement dependent on the first strand's pattern. The nitrogen bases guanine and cytosine must always line up across from each other. Likewise, adenine and thymine must always match up.

C. Since the top nitrogen base on the first chain was guanine, the top nitrogen base on the second strand must be cytosine. Place a cytosine on the top deoxyribose [Figure 4]. Finish the second strand by placing the appropriate nitrogen base on each sugar to correctly complement its opposing base.

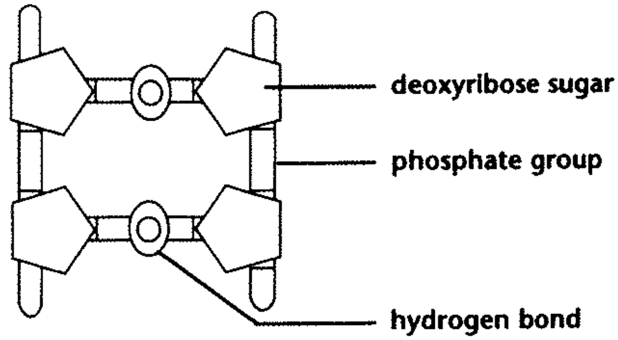


Figure 4
Partially completed DNA model

D. Nitrogen base pairs join via hydrogen bonding to create the "rungs" which run between the phosphate-sugar "tracks." Obtain eight hydrogen bonding plugs, and connect the two strands at their complementary nitrogen bases. This model is a portion of a DNA molecule.

3. The shape of DNA

A. DNA does not exist as the straight ladder you now have in front of you. Instead, the molecule twists around an imaginary vertical axis centered on the hydrogen bonds. Holding the DNA model at each end, twist the molecule to make a structure that resembles a spiral staircase.

B. This structure is called a double helix, and is a trademark characteristic of DNA strands. Allow your instructor to observe your model.

Refer to problems 1 through 3 on your Questions sheet.

Part II - Replicating a DNA molecule

4. Forming an original DNA molecule

A. Disassemble the DNA model formed in Part I. Construct a DNA model as shown in Figure 5.

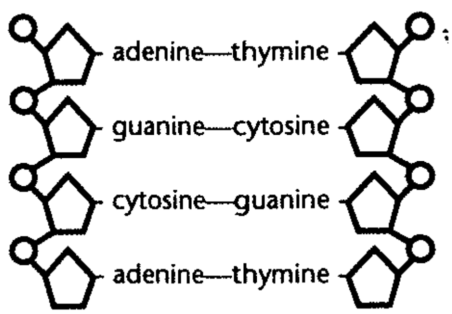


Figure 5
DNA example for replication procedure

B. Connect each remaining individual nitrogen base to a sugar piece, and add one phosphate tube to that sugar as well. Remember that a phosphate-sugar-nitrogen base is called a nucleotide. You should have eight nucleotides when you are finished.

5. Starting the replication process - "unzipping"

A. A DNA molecule begins to replicate itself by breaking the hydrogen bonds between the nitrogen bases. Once several consecutive bases have been split, the DNA strand gives the appearance of being "unzipped."

B. Break the bottom three hydrogen bonds of the model you have just formed, leaving the first connection together.

6. **Replication**

A. Free nucleotides are able to hydrogen bond to the unzipped DNA single strands, following the pairing guidelines discussed in Step 2. Using the individual model nucleotides from your selection, join a complementary nucleotide to each side of the bottom three unzipped segments.

B. Unzip the final, original hydrogen bond.

C. Complete the replication process by joining the remaining two (2) nucleotide molecules.

7. **Duplicity**

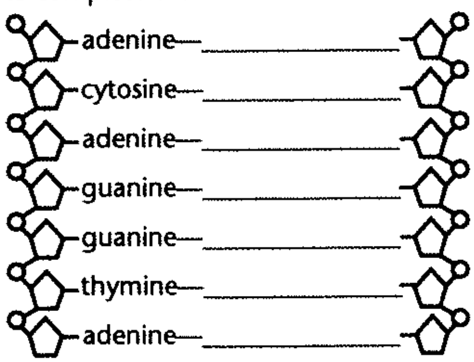
A. Compare the two DNA strands with your original [Figure 5]. Was the replication process exact? The efficiency of this synthesis allows DNA to be passed from generation to generation of organism with negligible margin of error.

Refer to problems 4 and 5 on the Questions sheet below.

Questions

1. Draw a diagram of your DNA molecule. Keep the illustration in a straight, "ladder" form, as seen in Figure 5; do not attempt to draw the double helix shape.

2. A partial strand of DNA has the nitrogen base pattern shown below. In the spaces provided, indicate what nitrogen base would be needed to complete the DNA.



3. The shape of a DNA molecule is called a "double helix." Describe this shape in your own words.

4. How is a DNA molecule replicated?

5. Heredity information is carried in the DNA of an organism, and genetic traits are passed from generation to generation through reproduction. How does the DNA replication process ensure information is transmitted accurately?