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Modeling DNA Structure & the Process of Replication

Objectives

- ***Assemble*** **models to demonstrate base pair structure**
- ***Model*** **the components of nucleotides**
- ***Model*** **DNA synthesis and replication by assembling nucleotides into double-stranded DNA**
- ***Demonstrate*** **DNA double helix structure**

Background

If you were asked to list the features that make you a unique individual, what would you list? You would probably share some of these characteristics with other people in your family but, unless you have an identical twin, those features would not be exactly the same as your relatives. The characteristics that make each of us "ourselves" are coded by a sequence of chemical building blocks in all of the cells of our bodies. This chemical is deoxyribonucleic acid or "DNA" for short. The building blocks of DNA, called "nucleotides," can be assembled in almost endless combinations – so, organisms as different as an elephant, a fern, an amoeba, and you, all share DNA. It's just arranged differently.

DNA nucleotides are composed of three smaller components which are covalently bonded: a five-carbon (i.e. pentose) sugar, a phosphate group and a nitrogen-containing base. There are four types of nucleotides, however. The only difference between them is the identity of the nitrogen-containing base. The phosphate group and deoxyribose - the five-carbon sugar - are always the same. By connecting nucleotides end-to-end in specific sequences, a code is developed which allows the cell to make proteins either for use within the cell or to be shipped outside the cell.

The four nitrogen-containing bases are adenine, guanine, cytosine and thymine. Two of these, cytosine and thymine, are single-ring structures and are called "pyrimidines."

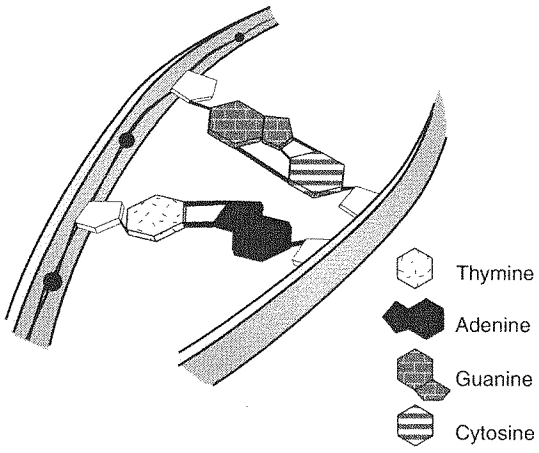

Figure 1

The other two bases, adenine and guanine, are double-ring structures and are called "purines." When nucleotides link together to form DNA, it is the sugar and phosphate groups which link the bases together in a long chain. The nitrogen-containing bases stick out to one side of the growing DNA chain, with the sugar and phosphate groups forming an unbroken strand on the opposite side (see Figure 1). Bases on adjacent strands of DNA can pair up to form one, double-stranded piece of DNA. This can only happen if each strand of DNA is complementary to the other. In order for bases to pair up, one must be a purine and the other must be a pyrimidine. In fact, in DNA, adenine only pairs with thymine (A-T) and cytosine only pairs with guanine (C-G). In other words, cytosine (C) is "complementary" to guanine (G), and thymine (T) is "complementary" to adenine.

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When complementary strands of DNA match up, hydrogen bonding occurs between complementary bases to hold the entire structure together. Because of the shapes of the molecules involved, the entire double-stranded DNA does not lie flat like a ribbon. Instead it forms a twisted structure, often called the "double helix."

Figure 2 - Double Helix

Although this structure is well known today, it was one of the great mysteries of the last century. This mystery was solved by a pair of scientists by the names of James Watson and Francis Crick, who successfully assembled a model of DNA using nucleotides. Most scientists up to that point in time had felt that the genetic material must have been made of protein – not nucleotides. Watson and Crick demonstrated to the world that the genetic diversity we see in all living creatures is a result of different arrangements of four nucleotides linked together into long strands of DNA called "chromosomes."

In this activity, you will build 3-dimensional models of the DNA bases and construct a model of the DNA double helix using the plastic manipulatives included in the kit. Although the materials used by Watson and Crick were somewhat different, their components (i.e. deoxyribose, phosphate, bases) were the same. You'll be recreating a historic moment in science by assembling this model successfully!

Safety Information

This lab activity uses small parts which may represent a choking hazard. Be sure that you follow teacher directions and take proper precautions when working with these parts.

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Activity 1

Constructing DNA Base Pairs

What you need

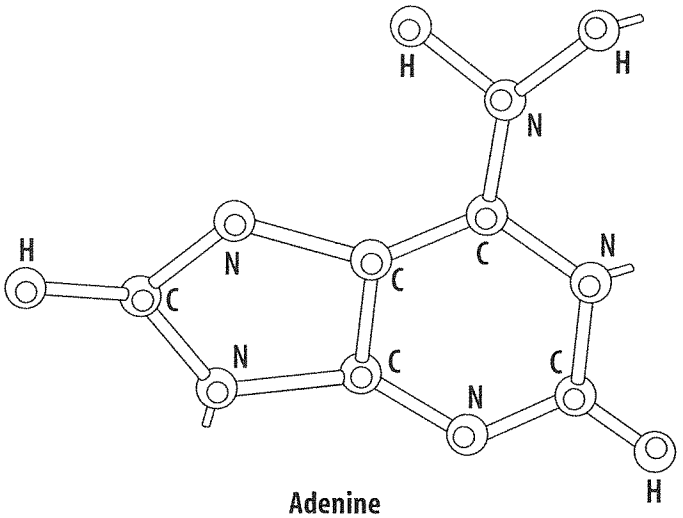
(per group)

- 9 Carbon, black (3 prongs)
- 1 Carbon, black (4 prongs)
- 7 Hydrogen, white (1 prong)
- 5 Hydrogen, white (2 prongs)
- 2 Nitrogen, blue (2 prongs)
- 6 Nitrogen, blue (3 prongs)
- 2 Oxygen, red (2 prongs)
- 1 Oxygen, red (1 prong)
- 32 Straws, white, 3.5cm flexible plastic

What to do...

Step 1

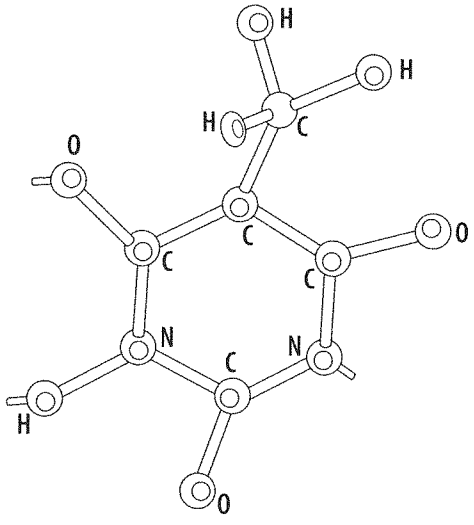
Construct a model of the base adenine using the illustration below as a guide:



Adenine

Step 2

Construct a model of the base thymine using the illustration below as a guide:



Thymine

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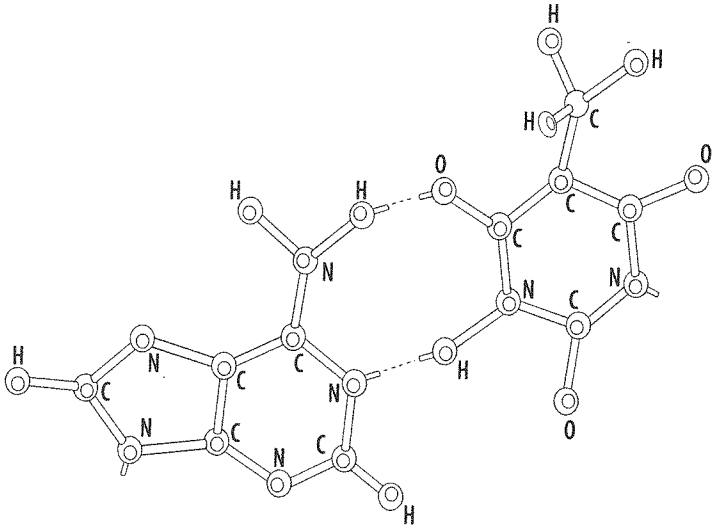
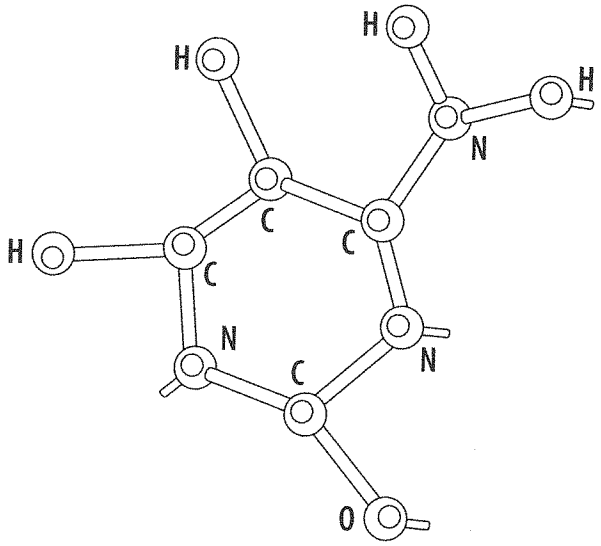
Step 3

Thymine and adenine are complementary bases, in that they can bond together via hydrogen bonds. Note that there are two hydrogen bonds that hold the adenine and thymine bases together. Use the illustration below to pair up adenine and thymine.



Step 4

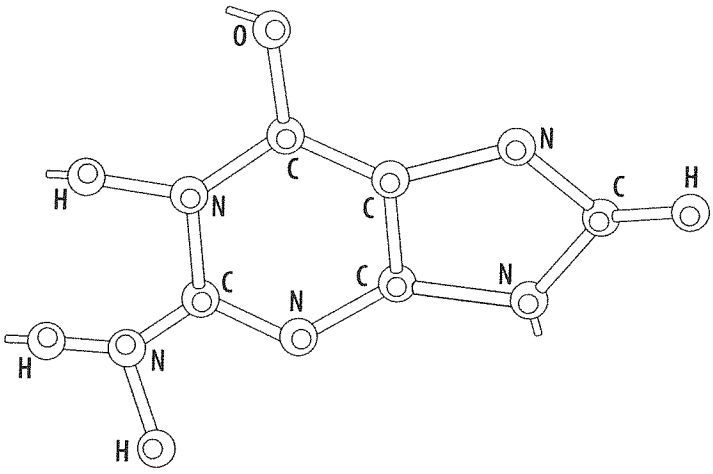
Disassemble the thymine and adenine base models constructed in the previous steps. Construct a model of the base cytosine using the illustration below as a guide:



Cytosine

Step 5

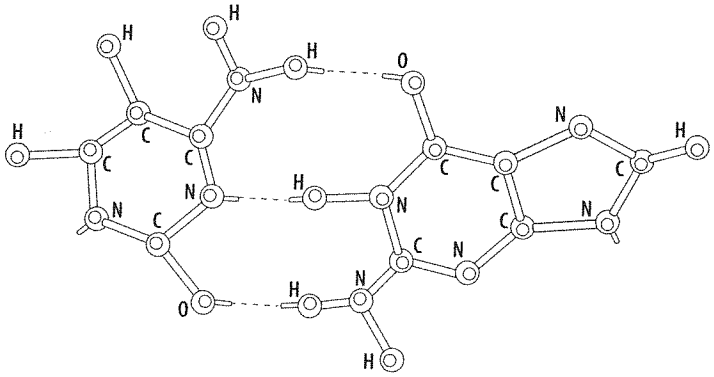
Construct a model of the base guanine, complementary base to cytosine, as shown in the illustration below:



Guanine

Step 6

Note that there are three hydrogen bonds that hold the guanine and cytosine bases together. Use the illustration below to pair up guanine and cytosine.



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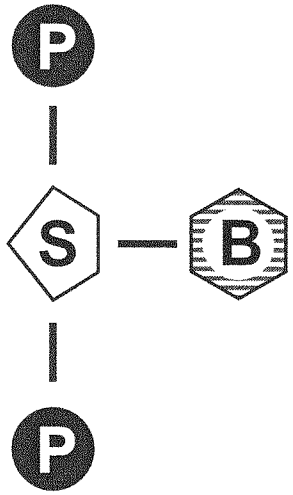
Activity 2

DNA Replication

A nucleotide consists of a nitrogen-containing base, a sugar group and a phosphate group held together by covalent bonds.



Note that the bases are represented by colored straws, the sugar group by a 4-prong carbon atom and the phosphate group by a 2-prong yellow manipulative. Nucleotides are the building blocks of DNA. Complementary bases are held together by hydrogen bonds.

Remember the base pair matching rules:

Guanine always pairs with **Cytosine**
Thymine always pairs with **Adenine**

Use the following color scheme:

Adenine = Blue
Thymine = Gray
Guanine = Red
Cytosine = White

What you need

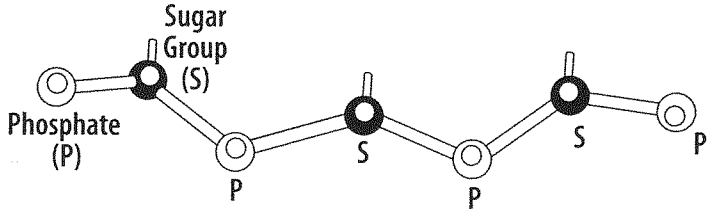
(per group)

- 5 Hydrogen - Hydrogen bonds, white (2 prongs)
- 8 Phosphate groups, Yellow (2 prongs)
- 16 Straws, white, 3.5cm flexible plastic
- 3 Straws, red, 3.5cm rigid plastic
- 3 Straws, white, 3.5cm rigid plastic
- 2 Straws, gray, 3.5cm rigid plastic
- 2 Straws, blue, 3.5cm rigid plastic
- 10 Sugar groups - Carbon, black (3 prongs)

What to do...

Step 1

Construct the "backbone" of the DNA by linking the phosphate groups with the sugar groups as shown in the illustration below:



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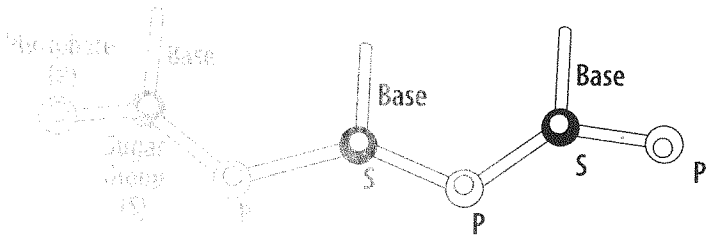
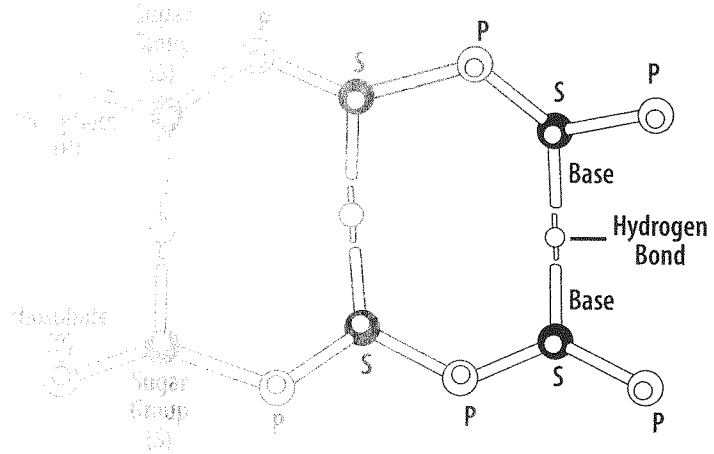
Step 2

Attach a base to the prong of each sugar group.



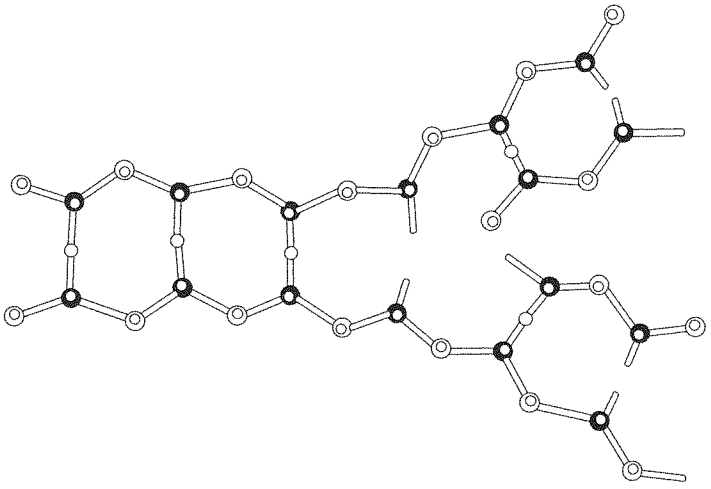
Step 3

Select complementary nucleotides and join them to the partially unzipped DNA you assembled in Steps 1 and 2. Pair complementary bases using the hydrogen bond connectors as shown below:



Step 4

During DNA replication, the double-stranded DNA molecule unwinds and unzips. As it unzips, each single-stranded DNA replicates forming two complete double DNA strands.



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Activity 3

DNA Double Helix

What you need

(per group)

- Assembled double-stranded DNA from Activity 2
- 1 Silver (4 prongs) to form base
- 3 Straws, white, 3.5cm for legs on base (flexible plastic)
- 1 Straw, green, 20cm rigid plastic

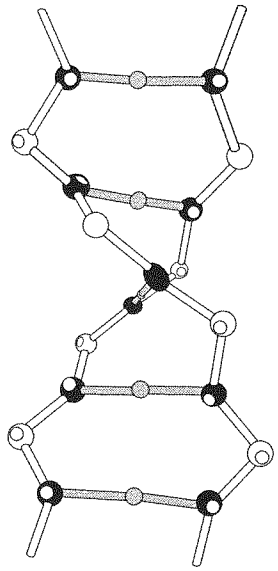
What to do...

Step 1

The secondary structure of DNA is a double helix, with hydrogen bonds bridging the two strands. Insert the long straw through the hydrogen bonds of the DNA double-stranded molecule that you assembled in the previous activity.

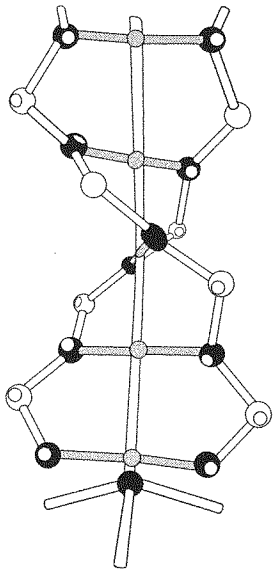
Step 2

Twist one of the rungs of the ladder counter clockwise to form the double helix structure.



Step 3

To support your DNA double helix model, prepare a base. Insert a 4 prong silver plastic manipulative on one end of the long straw and then attach a 3.5cm piece of straw to each of its four prongs.



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Questions

1. What does the term "complementary" mean in base-pairing?

2. Why isn't it possible for adenine to pair with cytosine or guanine?

3. What type of chemical bond is found between the phosphate group, sugar group, and base of a nucleotide?

4. What type of chemical bond is found between the strands of the DNA molecule?

5. What is a strand of DNA which functions as a section of the genetic code called?

6. What makes one gene different from the next gene within a chromosome?

7. What do you think must happen to the double strand of DNA when a cell makes a copy of itself?

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Going Further

Keeping in mind what you learned about complementary base-pairing, find out what is meant by the sentence "DNA replication is semi-conservative".

Chemically, RNA is very closely related to DNA. Research the major differences between RNA and DNA. What is RNA used for within a cell? How many types of RNA are there?

Investigate further how DNA fingerprints are used to diagnose inherited disorders, develop cures for inherited disorders, personal identification, determine familial relationships and to determine how newly discovered species are related to other organisms on earth.

Investigate further the social, legal and ethical implications surrounding DNA technology.

Learn and Read More About It

Ulf Lagerkvist. *DNA Pioneers and Their Legacy.* Yale University Press, 1998.

Lev Liapin. *Unraveling DNA: The Most Important Molecule of Life.* Perseus Press, 1997.

Paul Strathern. *The Big Idea: Crick, Watson, and DNA (Strathern, Paul, Big Idea.)* Anchor Books, 1999.

Borin Van Loon. *DNA: The Marvellous Molecule.* Parkwest Publishing, 1991.

James D. Watson. *The Double Helix: A Personal Account of the Discovery of the Structure of DNA.* New American Library Press, 1991.

Rainis and Nassis. *Biotechnology Projects for Young Scientists.* Danbury, CT: Franklin Watts, 1998.

Sherrow, Victoria. James Watson and Francis Crick: *Decoding the Secrets of DNA.* Woodbridge, CT: Blackbirch Press, 1995.

Neat Websites

Cold Spring Harbor Laboratory
http://vector.cshl.org/resources/aboutdnafingerprinting.html

The Genome Database
http://www.gbd.org/

General Genetics Information
http://gslc.genetics.utah.edu/students.html

Information on DNA, genes and human genome
http://www.bis.med.jhmi.edu/Dan/DOE/prim1.html

Information on genes and DNA double helix structure
http://falcon.cc.ukans.edu/~jbrown/gene.html

Information on the Human Genome Project
http://www.ornl.gov/hgmis/education/students.html