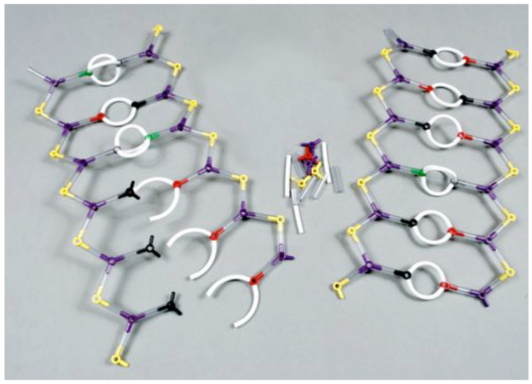
Super Models



Deoxyribonucleic Acid (DNA)

Molecular Model Kit

Recommended for ages 10-adult

⚠ **Caution:** Atom centers and vinyl tubing are a choking hazard. Do not eat or chew model parts.

Kit Contents:
25 purple 3-peg sugar
25 yellow 2-peg phosphate
9 red 3-peg adenine
9 black 3-peg thymine
5 green 4-peg cytosine
5 silver 4-peg guanine
75 clear, 1.25″ covalent bonds
31 white, 2″ hydrogen bonds

Related Kits:
Nucleic Acid Bases Molecular Model Kit
Nucleotides Molecular Model Kit

Replacement and Expansion Parts
Customized Kits

Phone: (806) 438-6865

E-Mail: etishler@rylerenterprises.com

Website: www.rylerenterprises.com

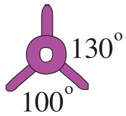
Address: 5701 1st Street, Lubbock, TX 79416

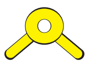
THE BASICS — AND A BIT BEYOND — OF DNA (A lab guide to understanding DNA)

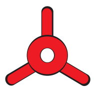
PART I: LEARNING THE PARTS OF DNA.

DNA is a double stranded **polymer** of **nucleotides**. A polymer is a long strand of repeating parts. In DNA, the repeating parts are called **nucleotides**. A nucleotide is made of a sugar called **deoxyribose**, a charged part (called an **ion**) of a molecule of **phosphate**, and one of the following **nitrogenous bases**: **adenine (A), thymine (T), cytosine (C), or guanine (G)**. They are called nitrogenous because they contain nitrogen.

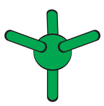
This kit supplies you with color-coded and bond parts as follows.

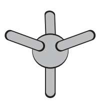
Sugar (deoxyribose) 

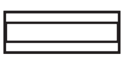
Phosphate ion, 

Adenine (A), 

Thymine (T), 

Cytosine (C), 

Guanine (G), 

Clear bond 

White (hydrogen) bond 

PART II: PUTTING THE PARTS TOGETHER.

EXERCISE I: IDENTIFYING THE PARTS OF DNA.

Without looking at the above diagrams, identify the parts that represent deoxyribose, phosphate, adenine, thymine, cytosine, and guanine.

EXERCISE II: MAKING A NUCLEOTIDE.

Assemble one nucleotide by placing a piece of clear tubing on the purple sugar-molecule peg that is at the top of the 130° angle farthest away from the other two pegs as pictured in Fig. 1. The tubing represents a chemical bond.

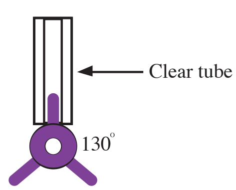


Fig. 1 Attaching a bond to deoxyribose.

Next, insert a peg of a thymine into the bond you just put on the sugar molecule. In order to complete the nucleotide, put clear-tubing bonds on the deoxyribose molecule pegs that are closest together, and place a yellow phosphate peg into either of these clear bonds. The phosphate is now on the **5´ carbon** of the nucleotide that you have just made (5´ is read five prime-the symbol ´ is called "prime"). The nucleotide is called a 5´ phosphate deoxyribonucleotide. This complicated name means that 1) the phosphate is bonded to the 5´ carbon of the sugar molecule called deoxyribose, and 2) there is a nitrogenous base attached to the sugar – see Fig. 2. The use of the purple-three-peg-plastic piece simplifies the model building, so for now we cannot actually see the 5´carbon atom.

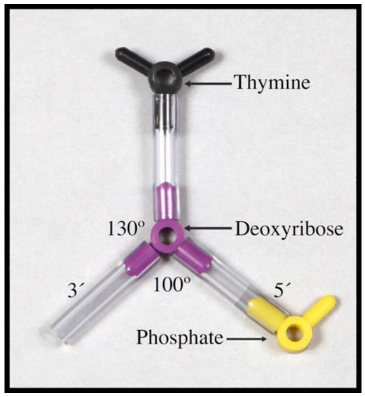


Fig. 2 A 5′ phosphate deoxyribonucleotide.

EXERCISE III: MAKING MORE NUCLEOTIDES.

Construct 25 more nucleotides from the remaining parts and clear plastic bonds. They will look similar to the nucleotide in Fig. 2, but in some there will be a different base in the place of thymine. See Fig. 3 below.

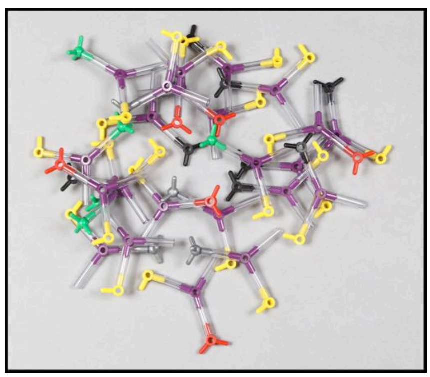


Fig. 3 25 5′ phosphate deoxyribonucleotides.

EXERCISE IV: MAKING A STRAND OF 12 NUCLEOTIDES.

Connect the yellow phosphate of the thymine (black) nucleotide to a 3′ bond on a sugar of an adenine (red) nucleotide. You have just made a dinucleotide which should resemble the one in Fig. 4. From left to right, the order is T A.

Fig. 4 A dinucleotide.

Continue to attach additional nucleotides to each other until you have a strand of 13. Your model should now be a duplicate of the strand shown in Fig. 5. You should have the same order of bases (TAAGTGACTCGTA). The strand is called an oligonucleotide.

Fig. 5 13 bases in an oligonucleotide of DNA.

<u>EXERCISE V: MAKING A DOUBLE STRANDED DNA MOLECULE.</u>

To complete a DNA molecule, you will now attach the remaining nucleotides to their partners (**complements**) on the strand of 13 nucleotides that you just made. Put **hydrogen bonds** (white tubes) on both of the unattached pegs of the base (T) of the first nucleotide (on the **3′** end) of the chain. Do the same for all of the remaining bases of the single strand. Connect the bases of all unattached nucleotides to the hydrogen bonds according to the following scheme: <u>**Red is bonded to Black with two hydrogen bonds**</u>**;** <u>**Green is bonded to Silver with three hydrogen bonds**</u>**.** The 5′ end of the just-added nucleotide should be on the left side. See Fig. 6.

Fig. 6 Making hydrogen bonds to the first four bases of the original oligonucleotide.

Continue to attach nucleotide bases to their complements with hydrogen bonds as you just did. When you are finished adding the remaining 11 nucleotides, insert the phosphates into the clear tube bonds on the sugar next to each phosphate. The double stranded DNA you just made is called a **duplex**. Compare the diagram of a DNA duplex in Fig. 7 with your model. You MUST have to have the same order of bases. Be sure that **RED IS BONDED TO BLACK, AND GREEN IS BONDED TO GREY.**

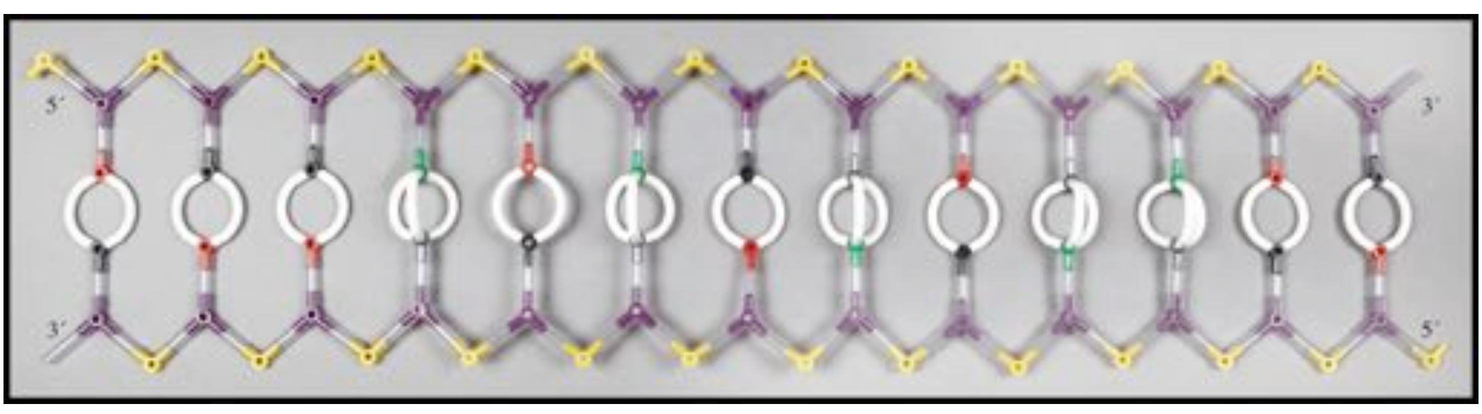


Fig. 7 The completed DNA molecule.

You have completed construction of a molecule of **DNA**. Look to the left side of Fig. 7; there is a T with an A above it. Since A (adenine) and T (thymine) are bases, this is called a **base pair**. There are 13 base pairs shown in the diagram. Your model should have a double strand with 13 base pairs. Make sure that you have obeyed the rules of DNA and paired an adenine (A) with a thymine (T), and paired a cytosine (C) with a guanine (G).

Notice that the two halves of the molecule run in opposite directions, that is the bottom half starts at 3´ on the left and proceeds to 5´ on the right. The top half is arranged with 5´ on the left and 3´ on the right.
This alignment is important to the functioning of the DNA molecule, and it is called an **antiparallel** arrangement.

Three features of DNA can be seen in the model. First, there are two kinds of bonds. The clear, thicker tubes represent strong-chemical bonds that can occur between almost any two types of atoms. The longer, white tubes are for hydrogen bonds that are weaker and involve the sharing of hydrogen atoms. Hydrogen bonds can easily be broken by heat, radiation or chemical agents. Second, there are two hydrogen bonds between A and T, while three hydrogen bonds occur between C and G. Organisms that live in hot springs have more C and G in their DNA, as you can imagine. And finally, the molecule resembles a ladder with the "rungs" represented by the bases and the "sidepieces" or "backbones" are made of alternating sugar-phosphate molecules (-s-p-s-p- and so on).

Congratulations! Now you are acquainted with the basics of DNA composition and structure.

PART III: MORE ABOUT DNA STRUCTURE.

The hydrogen bonding between the bases of the nucleotides forces the DNA to take on the form of a **helix** (spiral). Since DNA is made of two strands, we call the molecule a **double helix** (sometimes it is called a duplex). Below, in Fig. 8, there is a metal spring (not supplied) on the left and a portion of a DNA molecule on the right. A helix may be right-handed or left-handed. It is left-handed if, when seen from the top, it turns in a counter-clockwise direction. It is right-handed if, when seen from the top, it turns in a clockwise direction.

Observe that the metal spring and the DNA double helix are right-handed. This form of DNA is called B-DNA, and it is one of several possible forms of the molecule.

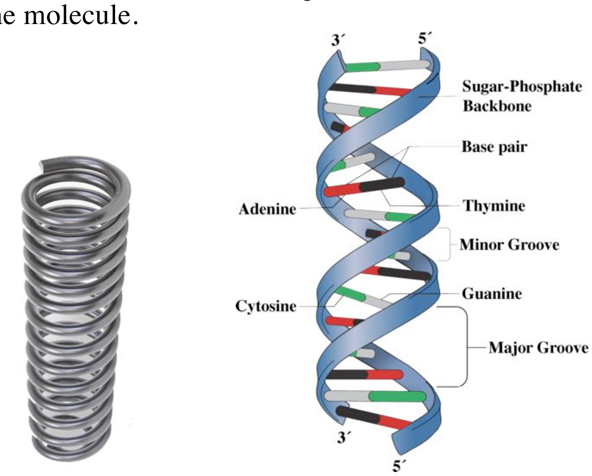


Fig. 8 A right-handed metal helix and a part of a right-handed DNA molecule.

Two new features of DNA become obvious when you examine Fig. 8. One is the double helix which is similar to a spiral staircase, not a twisted ladder, and second, there are two sizes of grooves in the molecule. The larger is known as the **major groove**, while the smaller is called the **minor groove**.

In a living cell, DNA has two functions: 1) Make exact copies of itself prior to cell division or for other purposes, and 2) Control the development and the operation of the cell from its birth up to and including its death.

This kit will be helpful in understanding the first of the two functions. A separate kit is available for studying the second function.

PART IV: REPLICATING A DNA MOLECULE.

Using zippers of two different colors, we can see the overall plan for the steps used to make two exact copies of a DNA molecule. The replicative process is called semi-conservative replication because the original two strands of the double helix are retained; they are present in the two new DNA daughter strands. See Fig. 9 below for the steps in the procedure.

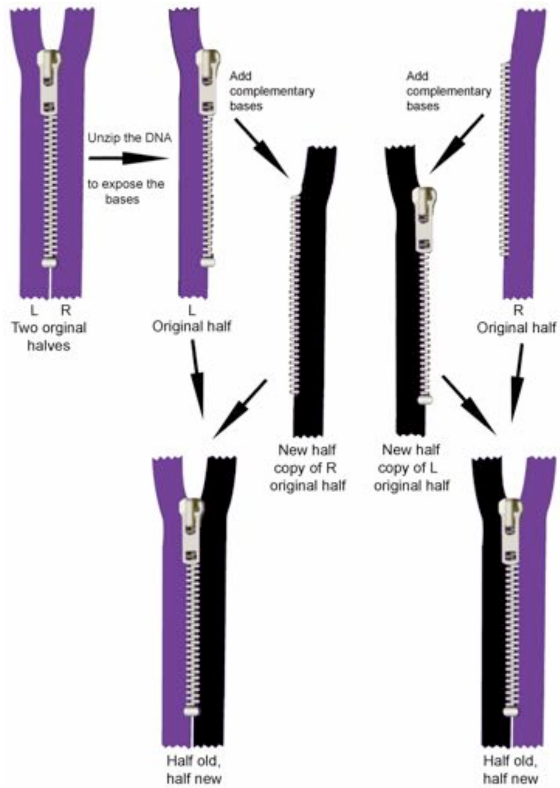


Fig. 9 Using zippers to demonstrate semi-conservative replication of DNA.

STEP I: PREPARING SIX BASE PAIRS.

In order to show the duplicating (replicating) of a DNA molecule, make a DNA model with the base order as in Fig. 10, (BOTTOM STRAND: 3´ TAAGTG 5´).

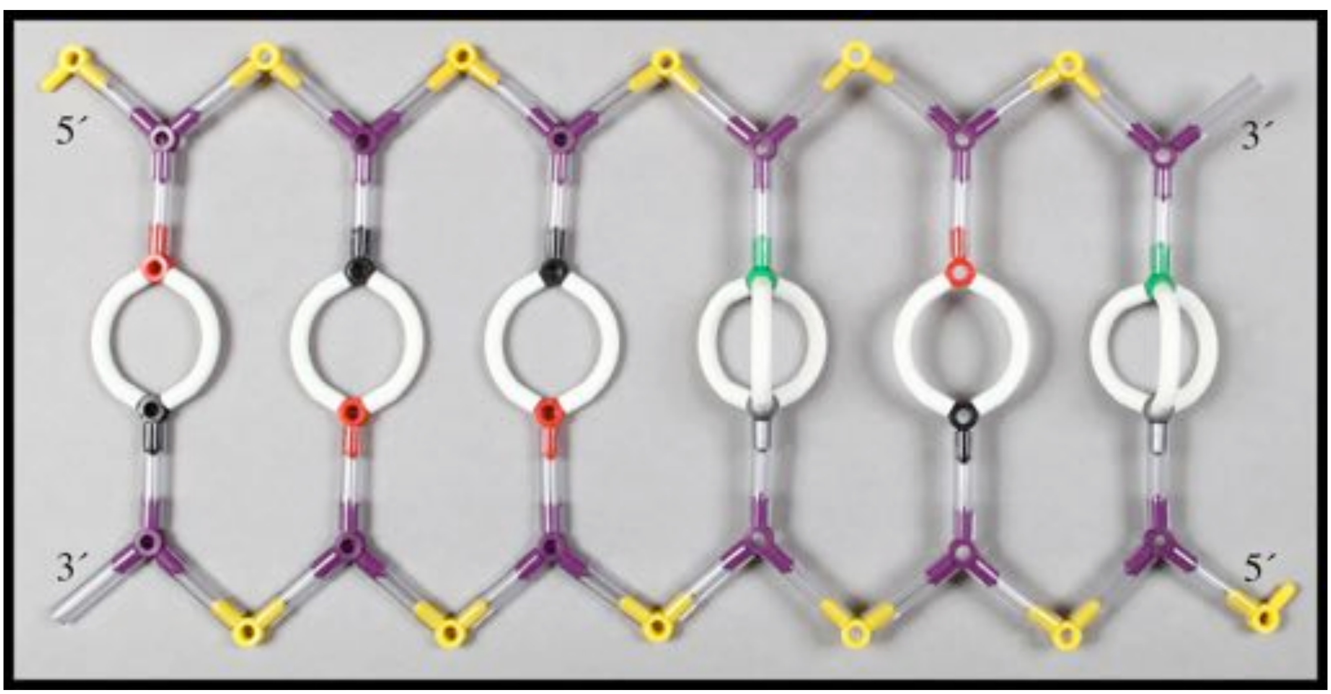


Fig. 10 A 6 base pair double helix (duplex) prepared for replication.

STEP II: UNZIPPING THE DNA.

Starting from the right hand side of the molecule, separate the hydrogen bonds from the bases on the lower strand. In the actual cellular process, the bonds would be completely removed from both strands. But to save time, we only detach the tubes from one strand. Hydrogen bonds are weaker than ordinary covalent bonds, and hydrogen bonds are more easily broken.

As the two halves of the duplex separate, a space called the **replication fork** is formed. See Fig. 11.

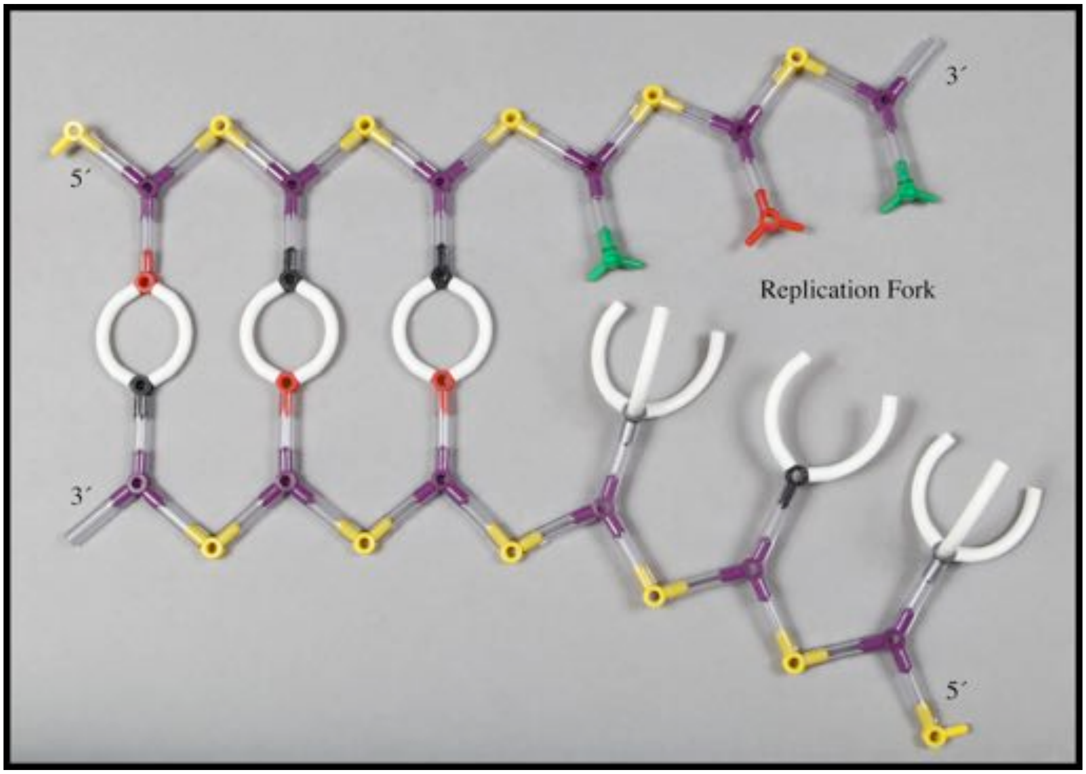


Fig. 11 Forming a replication fork and separating the duplex.

After complete separation, the model should look like the photo in Fig. 12.

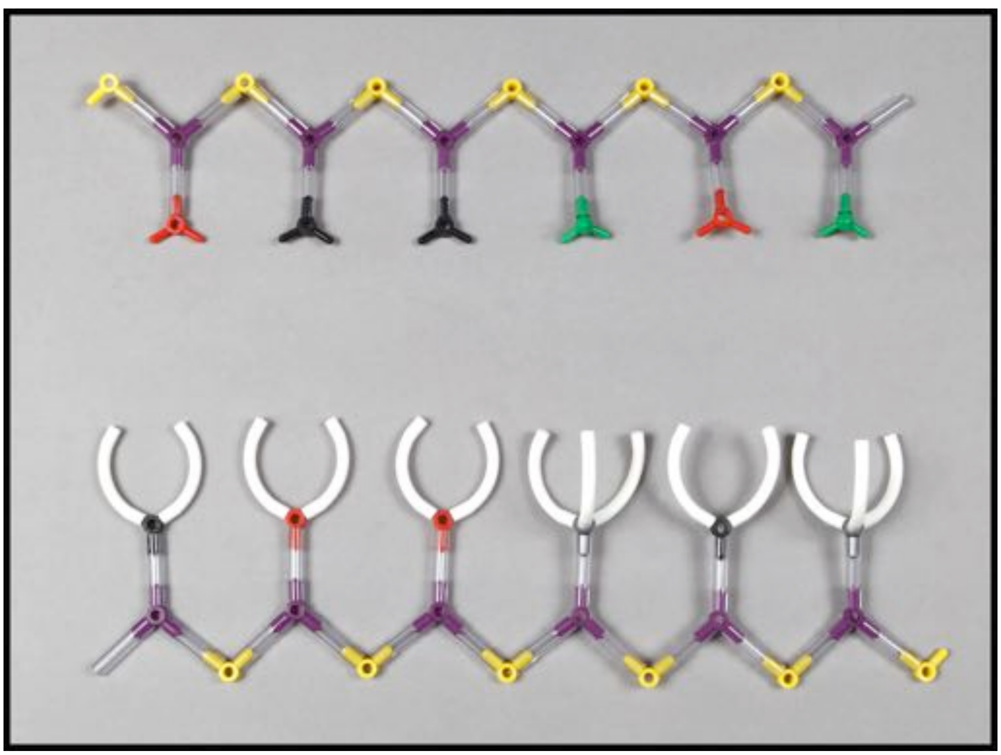


Fig. 12 The completely separated double helix (duplex).

STEP III: ADDING NUCLEOTIDES TO THE SEPARATED DNA STRANDS.

Now we face the problem of where to place the new nucleotides to be added to the old strands. The solution is related to 1) an energy requirement and 2) the availability of exposed bases on the original strands.

Building any complex structure from simpler parts, be it putting up a house, or making more DNA, uses energy. Constructing a house uses human and machine energy. Making DNA utilizes chemical energy.

Every nucleotide to be added to the original DNA strand starts out as a sugar bonded to a base and to *three phosphates*. The three phosphates have high chemical energy that can power the building of a new strand of DNA.

The three phosphates are always on the 5´ end of the sugar of any nucleotide. The placement of the phosphates, and the release of energy is illustrated in the next figure, Fig. 13.

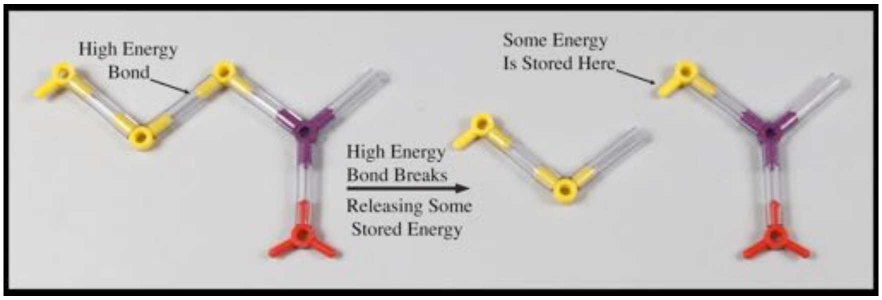


Fig. 13 Releasing the energy to form new DNA.

The placing of a new nucleotide is determined by the opening of the replication fork which exposes bases on the original DNA strand and by the position of a 3´ end of the strand. This is illustrated in the next diagram, Fig. 14.

Only the phosphates on the 5´ end of a nucleotide have the required energy to make more DNA. (Keep in mind that the phosphate is never found on the 3´ end of the sugar.) A handy memory device to determine the direction in which to add new bases is “read up” (3´ to 5´ on the old strand) and “write down” (5´ to 3´ on the new strand).

Notice that the bottom original strand and the top original strand add nucleotides in opposite directions. The process is complex: it involves formation of a replication bubble, replication forks, leading and lagging strands, and Okazaki fragments.

OPTION I: SIMPLIFIED VERSION
After separating the two halves of the model, just add nucleotides, one at a time, to the exposed bases. See Fig. 14.

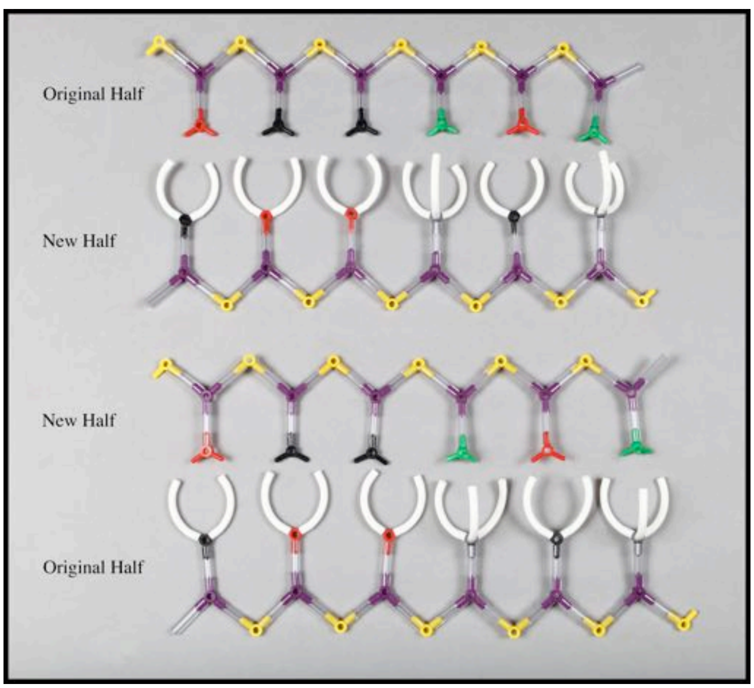


Fig. 14 Adding new nucleotides to the original, separated DNA halves.

The end result appears in Fig. 15.

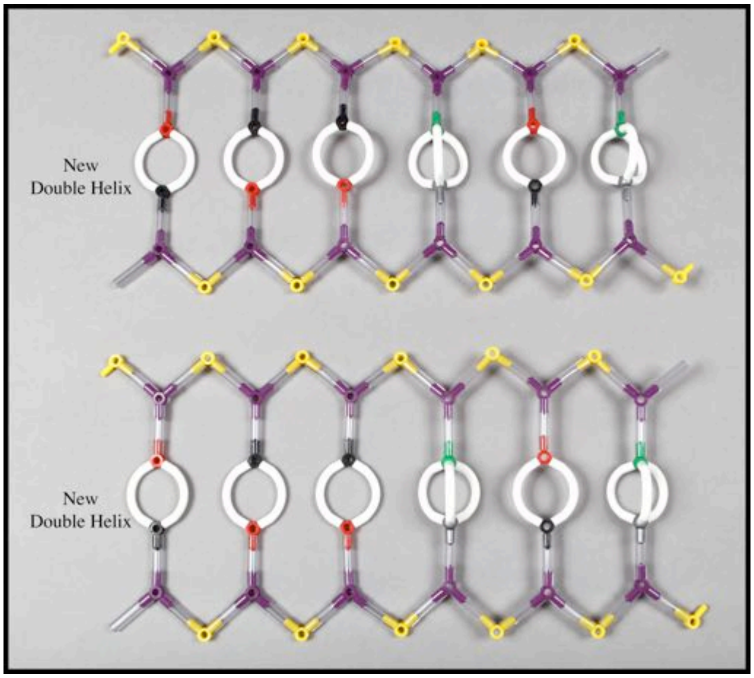


Fig. 15 Two new replicated DNA molecules.

<u>OPTION II: AN ADDED COMLEX FEATURE</u>

At the 3´ ends of the separated molecule, place some kind of a clip (here we added a clothes-pin) to simulate an RNA primer. In the cellular process, a 10 to 20 base long strand of RNA will be bonded to the exposed bases of the DNA by an enzyme called primase. The primer addition follows the same "read up" (3´ to 5´ on the old strand) and "write down" (5´ to 3´ on the new strand) rules. The primer always has a 3´ bond available for bonding with a 5´ end of new nucleotide.

The first new DNA nucleotide to be added is bonded to the 3´ of the primer (**<u>not actually done on the model</u>**). Then proceed to add one nucleotide at a time to the growing new chain of nucleotides, as seen in Fig. 16. The end result is the same as in Fig. 15. In each of the new growing DNA chains, there is a 3´ tube available to accept the 5´phosphate of the next nucleotide to be added. Once the DNA nucleotides are added, the RNA primers are removed and replaced with DNA nucleotides. The actual process is more complicated as illustrated in OPTION III, below.

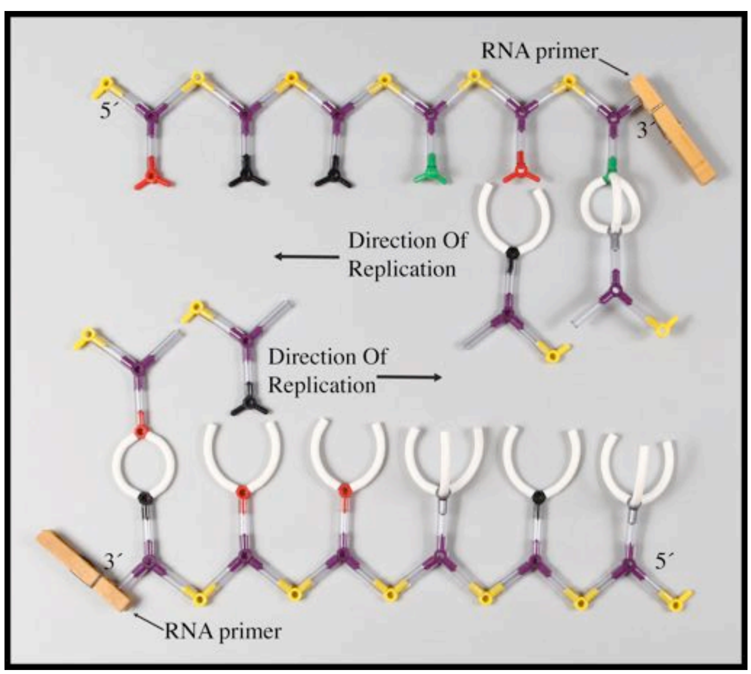


Fig. 16 Showing RNA primers before adding new complementary bases.

OPTION III: THE MOST LIFE-LIKE VERSION

See Fig. 17 for a guide to the following instructions. Make a replication fork on the right side of the model exposing four bases on each of the strands of the model. Place a clip representing an RNA primer on the 3´ end of the top strand. Place a clip representing a primer on the 3´ end of the second from the right nucleotide of the bottom strand. After the first new nucleotide on the top is bonded to the RNA primer, the next nucleotide can be bonded as well. The first nucleotide added to the bottom strand of DNA is the one closest to the RNA primer. That is because the 5´ phosphate of the new nucleotide must bond to an existing 3´ bond. The 3´ bond is provided by the primer. A second nucleotide can be bonded on the bottom strand now. The resulting two added nucleotides on the bottom half constitute a short length called an Okazaki fragment.

A third nucleotide can now be bonded to the growing new DNA chain on the top half of the model. A third nucleotide can not be bonded to the bottom half of the model. Why? It is the incoming nucleotide with a high energy 5´ phosphate (see Fig. 13) that has to bonded to a 3´ tube already in place, but none is available.

The problem is solved by placing an RNA primer to the left of the 3rd nucleotide from the right on the bottom half of the model. See Fig. 18.

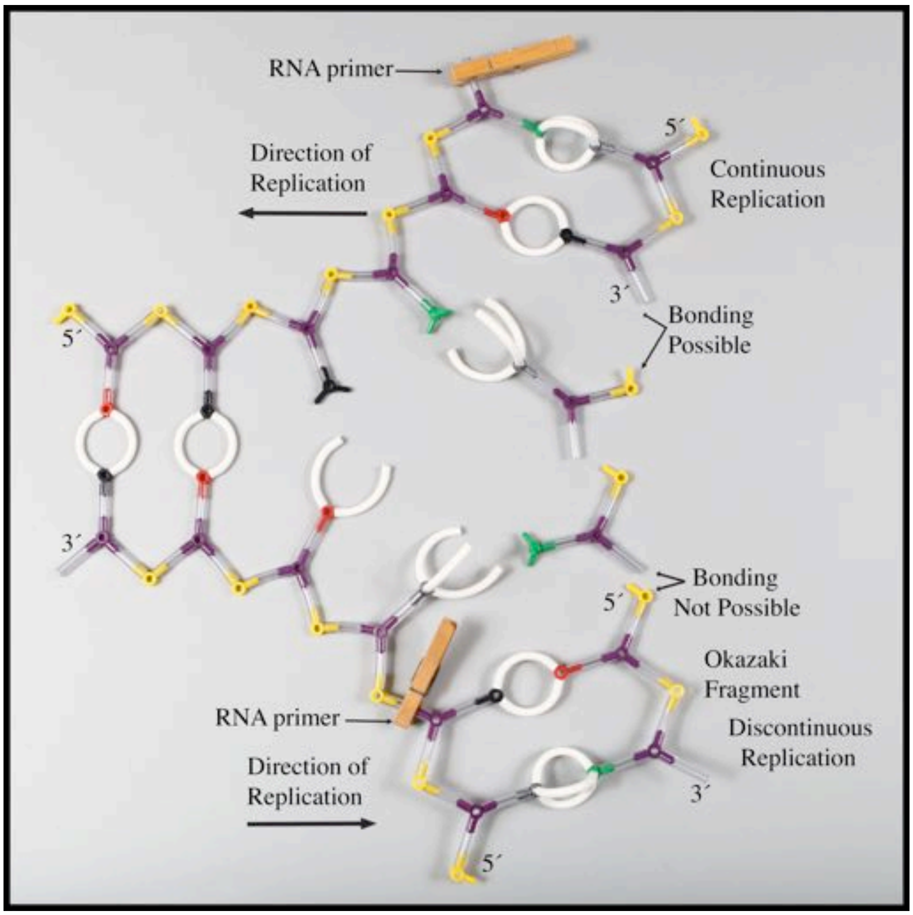


Fig. 17 Bonding RNA primers and nucleotides to separated DNA halves.

The first RNA primer has been removed from the bottom strand and a new RNA primer has been attached one nucleotide to the left. The growth of the new top strand (the leading strand) continues without stopping. The growth of the bottom strand (the lagging strand) has starts and stops because new 3´ bonds are exposed intermittently. The end result is the same as in Fig. 15.

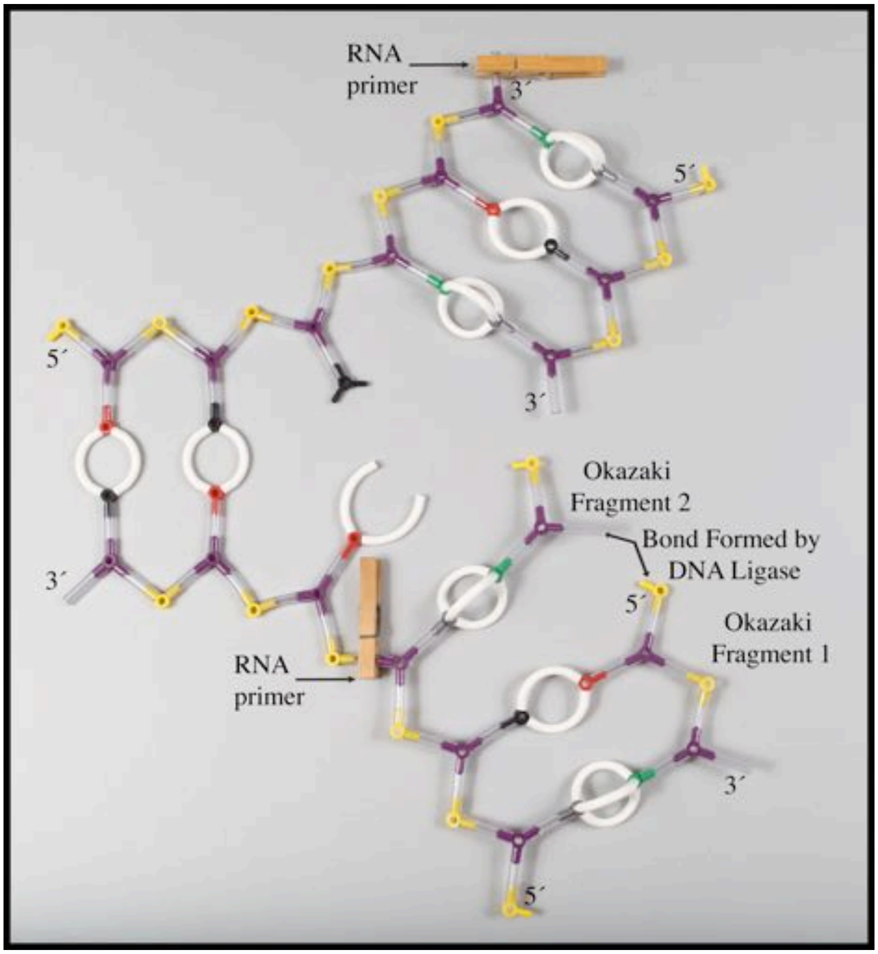
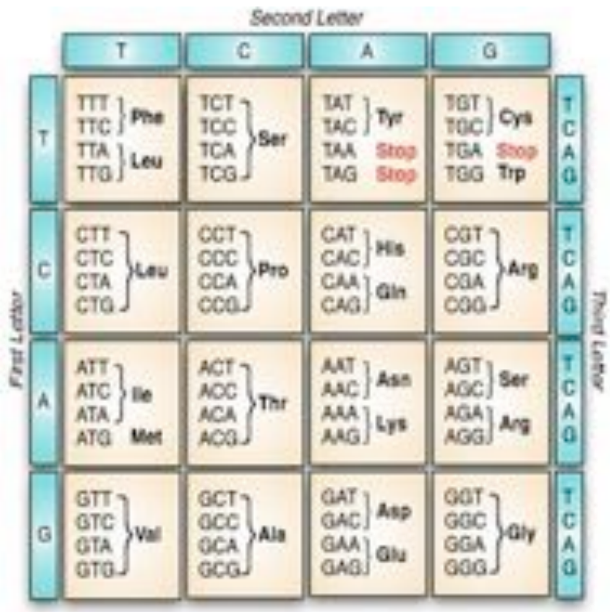


Fig. 18 Growth of the leading and lagging strands.

TABLE OF THE GENETIC CODE AND AMINO ACIDS TO BE USED IN PROTEIN AND MUTATION INVESTIGATIONS.



Amino Acids and their abbreviations.
- Ala-Alanine
- Arg-Arginine
- Asn-Asparagine
- Asp-Aspartic acid
- Cys-Cysteine
- Gly-Glycine
- Gln-Glutamine
- Glu-Glutamic Acid
- His-Histidine
- Ile-Isoleucine
- Leu-Leucine
- Lys-Lysine
- Met-Methionine
- Phe-Phenylalanine
- Pro-Proline
- Ser-Serine
- Thr-Threonine
- Trp-Tryptophan
- Tyr-Tyrosine
- Val-Valine

Fig. 19 The genetic code and 20 common amino acids.

The genetic code requires that the information for the making of proteins, and therefore controlling cell structure and function, be read from the DNA in triplets, i.e. three bases at a time. The triplets are called codons.

PART V: AMINO ACID SEQUENCE FROM DNA MOLECULE.

What is the order of amino acids coded for by the first model built (as seen in Fig. 7)?

PART VI: A POINT MUTATION TO BE DONE ON PAPER.

One of the common genetic conditions in people that populate areas of the globe where malaria is a problem is sickle cell hemoglobin. Possessing two genes (being homozygous) for the condition can be life threatening. The normal gene calls for the amino acid glutamic acid to be in the sixth position of a β–polypeptide chain from the left. A mutated gene inserts valine in stead of glutamic acid. Two β–chains are incorporated into a hemoglobin molecule. When valine is present in hemoglobin, red blood cells containing the molecules become distorted into a sickle (crescent) shape. These cells break easily, plugging small vessels, and the blood fails to carry oxygen normally. The ensuing sickle cell anemia can then be fatal.

Which point mutation causes the change of glutamic acid to valine? READ THE CODE FROM 3´ TO 5´ ON THE BOTTOM STRAND.

Answer_____

1. 5´—CAA GTA GAA TGG GGG CTC—3´
   3´—GTT CAT CTT ACC CCC GAG—5´

2. 5´—CAG GTA GAG TGT GGC CTT— 3´
   3´—GTC CAT CTC ACA CCG GAA—5´

3. 5´—CAC GTG GAT TGT GGG CTC—3´
   3´—GTG CAC CTA ACA CCC GAG—5´

4. 5´—CAT GTA GAC TGA GGA CAT—3´
   3´—GTA CAT CTG ACT CCT GTA—5´

5. 5´—CAT GTA GAA TGC GGT CTC—3´
   3´—GTA CAT CTT ACG CCA GAG—5´

PART VI: THE DNA HELIX.

Two students holding a DNA model can demonstrate the primary coiling of the molecule in the B-DNA conformation with 10 base pairs per turn. Using the model this way shows the staircase-like twisting of both backbones of the B-DNA double helix around a common axis, rather than a twisted ladder arrangement.

PART VII: A CLOSER LOOK AT THE CHEMISTRY OF DNA.

One can get a very good understanding of the form and function of DNA without a knowledge of the intimate details of the arrangement of the atoms that make up the molecule. This section may be skipped if it does not help in your understanding of DNA, but it might be of some interest to seeing deeper into the complexity of this important molecule of life.

Because we started by making nucleotides, we will look at illustrations of the linking of three parts that went into their structure.

First we have the sugar, deoxyribose, which has five carbon atoms. The elements in the diagram are oxygen (symbol O), hydrogen (symbol H), and carbon (symbol C). The carbons, which are understood to be at the corners of the diagram, are labeled with numbers that are marked with a prime symbol (´), Fig. 21. The sugar, ribose, has an oxygen atom bonded to the 2´ carbon between the carbon and the hydrogen. De (without) oxy (oxygen), deoxyribose, lacks that oxygen.

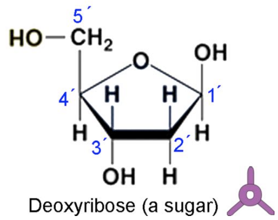


Fig. 21 Deoxyribose and the model part.

Next in making our model we bonded a base to the sugar. Fig. 22 is a molecular diagram of the base, adenine, which has its carbon atoms numbered. It should be clear now that we use prime markings on the numbers of the sugar to avoid confusion.

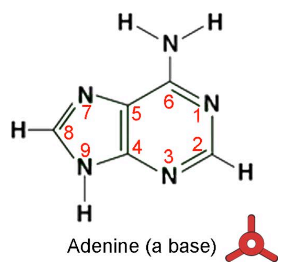


Fig. 22 Adenine and the model part.

At this time, it is not necessary for you to remember the numbering scheme of any molecular diagram, but keep in mind that if no atom is shown at a corner, a carbon atom is there.

Fig. 23 shows how the base is bonded to the sugar.

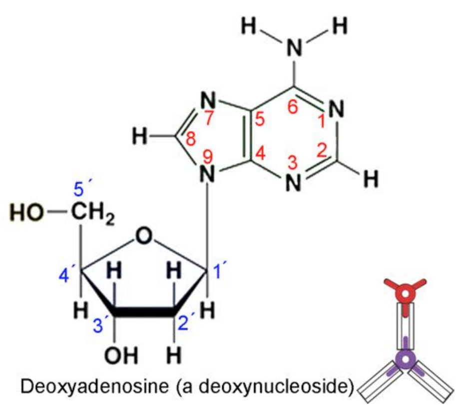


Fig. 23 Adenine bonded to deoxyribose and the model part.

To complete the nucleotide, we bond a phosphate ion (see Fig. 24) to the sugar. The P is the symbol for the element phosphorus. When in position, the phosphate defines the 5´ end of the nucleotide, as you can see in Fig. 25.

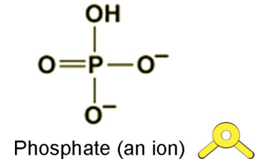


Fig. 24 A phosphate ion and the model part.

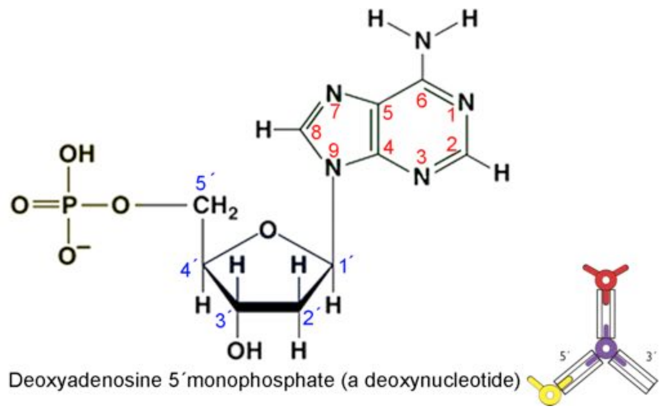


Fig. 25 A completed nucleotide and the model.

Fig. 26, below, has detailed molecular diagrams of the four bases of DNA.

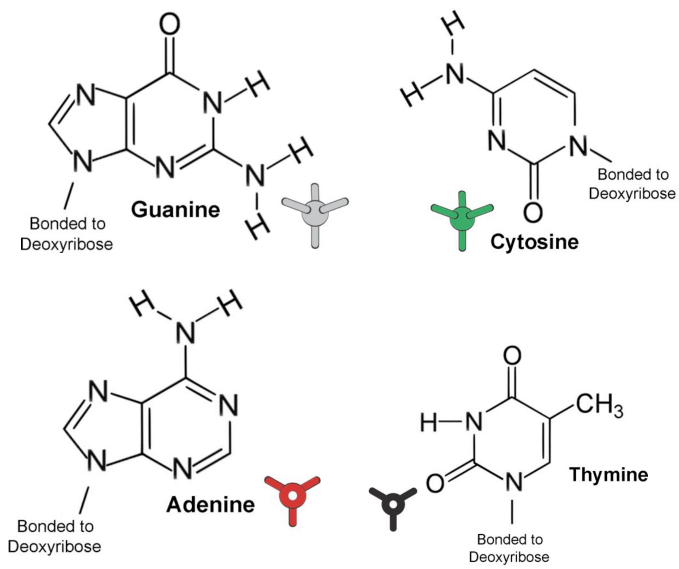


Fig. 26 The four nitrogenous bases of DNA.

Look again at Fig. 8, and review the meaning of the term base pair. There are three base pairs shown in a small section of DNA in Fig. 27. Observe how a hydrogen atom is shared between N and O, or between N and N atoms in a hydrogen bond.

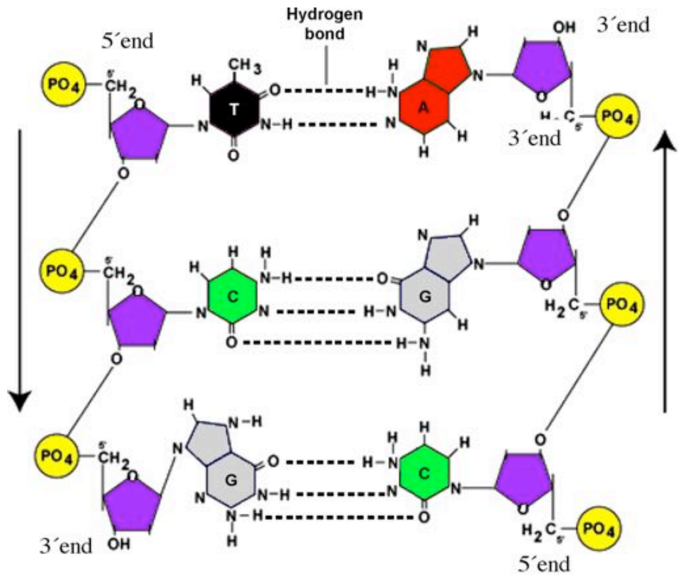


Fig. 27 Three base pairs, and 3´ and 5´ ends of the two halves of DNA.

ADDITIONAL INFORMATION

INTERESTING FACTS ABOUT THE HUMAN GENOME (THE TOTAL AMOUNT OF OUR DNA IN ONE BODY CELL):

Number of genes ~25,000.

Number of base pairs -3.2 billion.

DNA in protein coding sequences (these direct the cell to make proteins) -1.5%

DNA in **other useful sequences** (these make several types of special RNA molecules and control other sections of DNA) -3.5%

Number of pseudogenes (mutated genes that no longer function) >20,000.

DNA in repeated regions, similar to a word in a sentence being retyped thousands of times. One of them named *Alu* is present in over one million copies in each of our cells. Repeats play different roles in cells, some are helpful, some not. They all have base pairs that have the same sequences. The average number of base pairs in a repeat is ~ 300. Amount of DNA repeats per cell ~50% of total.

ONLINE RESOURCES:

Many new terms are added in these videos, so you may want to watch them several times.

https://www.youtube.com/watch?v=2ymwAtu3rAM

https://www.youtube.com/watch?v=8kK2zwjRV0M

TERMS TO INVESTIGATE FOR A FULLER UNDERSTANDING OF DNA:

Antiparallel, parallel alignment of complementary strands
Centromere
Chromatin (euchromatin, heterochromatin)
Codon (anticodon)
Complementary base pairing
DNA gyrase
DNA helicase
DNA ligase
DNA polymerase I
DNA polymerase III
DNA strands (Coding-Noncoding, Sense-Antisense, Template-Nontemplate)
Double helix (DNA duplex)

TERMS TO INVESTIGATE FOR A FULLER UNDERSTANDING OF DNA (CONT'D):

Epigenetics
Genetic code (triplets, codons, redundantcy)
Helical forms (A, B, Z)
Histones
Major, minor grooves
Mutation
Nucleobases (purines, pyrimidines)
Nucleoside (monophosphate, diphosphate, triphosphate)
Numbers of units (monomer, dimer, oligomer, polymer)
Origin of replication
Primase
Replication (replication bubble, replication fork, leading strand, lagging strand, Okazaki fragment, RNA primer)
Structural hierarchy of DNA (primary — polynucleotide strand, secondary — double helix)
Telomere (telomerase)

ASSESSMENT TO ACCOMPANY "THE BASICS — AND A BIT BEYOND — OF DNA"

To find out what you know about DNA, and to find out how building the model increases your knowledge, choose the best answers to the following questions. **Prior to** assembly of the parts, place your answers in the blanks marked (before model), and **after** making the model, go through the questions again, and put your answers in the blanks marked (after model).

1. DNA is a long strand of repeating parts called ________(before model), ________(after model)
    a. nitrogenous bases
    b. deoxyribose
    c. nucleotides
    d. phosphate
    e. ribose

2. The sugar found in DNA is ________(before model), ________(after model)
    a. ribose
    b. adenine
    c. deoxyribose
    d. an ion
    e. glucose

3. The term "nitrogenous" means containing ________(before model), ________(after model)
    a. nitrogen
    b. neon
    c. a sugar
    d. nucleotides
    e. ions

4. Which of the following correctly lists the four bases of DNA? ________(before model), ________(after model)
    a. ribose, adenine, thymine, cytosine
    b. adenine, deoxyribose, phosphate, guanine
    c. adenine, guanine, cytosine, uracil
    d. guanine, cytosine, thymine, adenine
    e. cytosine, ribosine, thymine, guanine

5. In a nucleotide, the phosphate is bonded to ________(before model), ________(after model)
    a. a 1´ carbon atom
    b. a 2´ carbon atom
    c. a 3´ carbon atom
    d. a 4´ carbon atom
    e. a 5´ carbon atom

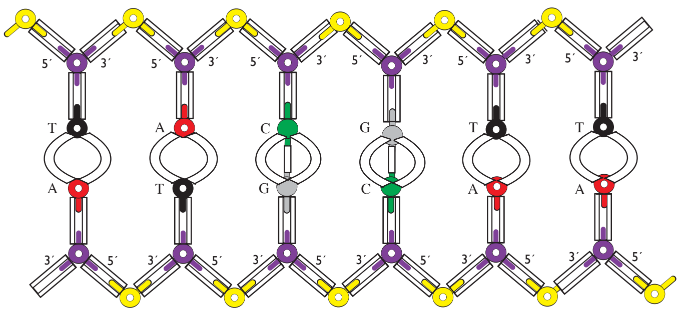
6. A nucleotide of DNA is composed of ________(before model), ________(after model)
    a. a nitrogenous base, deoxyribose, and a polymer
    b. ribose, a sugar, and phosphate
    c. ribose, phosphate, RNA, and a dinucleotide
    d. deoxyribose, phosphate, and sugar
    e. deoxyribose, phosphate, and a nitrogenous base

7. How many strands is a complete DNA molecule made from? ________(before model), ________(after model)
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5

8. Which of the following is a correct complementary base pairing? ________(before model), ________(after model)
   a. A-A
   b. C-C
   c. deoxyribose-deoxyribose
   d. A-C
   e. A-T

9. A complete DNA molecule looks like a ladder. What makes up the “side pieces” (“backbones”) of the ladder? ________(before model), ________(after model)
   a. nitrogenous bases
   b. nitrogenous bases and phosphate
   c. ribose and deoxyribose
   d. sugar and phosphate
   e. base pairs

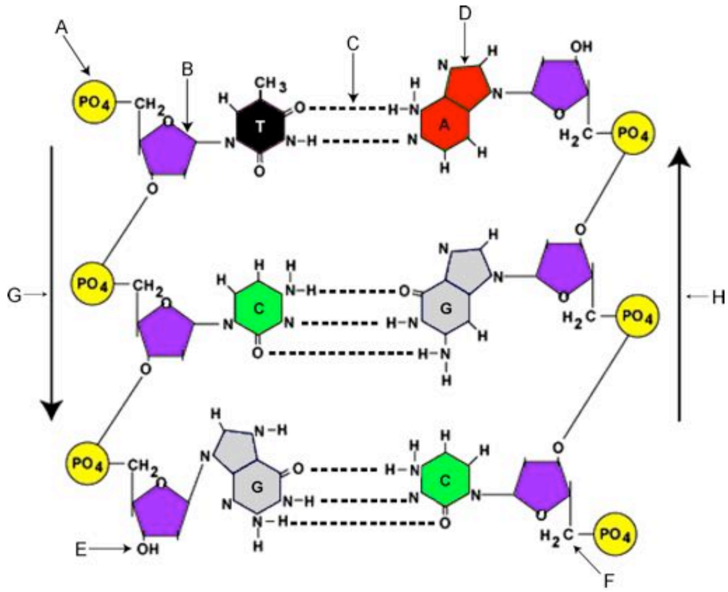
10. How many base pairs are in this diagram? ________(before model), ________(after model)



   a. 2
   b. 3
   c. 4
   d. 5
   e. 6

11. What type of a bond connects two complementary bases together? ________(before model), ________(after model)
   a. hydrogen
   b. phosphate
   c. deoxyribose
   d. nucleotide
   e. clear tube

The next seven questions are about the following diagram.



12. The letter A points to a ________(before model), ________(after model)
    a. ribose
    b. base
    c. hydrogen bond
    d. deoxyribose
    e. phosphate

13. B points to a ________(before model), ________(after model)
    a. ribose
    b. base
    c. hydrogen bond
    d. deoxyribose
    e. phosphate

14. C points to a ________(before model), ________(after model)
    a. ribose
    b. base
    c. hydrogen bond
    d. deoxyribose
    e. phosphate

15. D points to a ________(before model), ________(after model)
    a. ribose
    b. base
    c. hydrogen bond
    d. deoxyribose
    e. phosphate

16. To which end of the DNA molecule does E point? ________(before model), ________(after model)
    a. 1´
    b. 2´
    c. 3´
    d. 4´
    e. 5´

17. To which end of the DNA molecule does F point? ________(before model), ________(after model)
    a. 1´
    b. 2´
    c. 3´
    d. 4´
    e. 5´

18. The long arrows labeled G and H are pointing in opposite directions. Because of this arrangement, the two strands that make up DNA are said to be ________(before model), ________(after model)
    a. elongated
    b. antiparallel
    c. parallel
    d. twisted
    e. genetic

19. A replication fork occurs when the two strands of a DNA molecule are ________(before model), ________(after model)
    a. twisted
    b. parallel
    c. separated
    d. joined
    e. made 3´ prime

20. The energy to make a complex structure such as DNA is supplied by breaking bonds between ________(before model), ________(after model)
    a. sugars
    b. bases
    c. phosphates
    d. dinucleotides
    e. sugars and bases

ANSWERS TO ASSESSMENT QUESTIONS FOR
"THE BASICS — AND A BIT BEYOND — OF DNA"

1. b. nucleotides
2. c. deoxyribose
3. a. nitrogen
4. d. guanine, cytosine, thymine, adenine
5. e. a 5´ carbon atom
6. e. deoxyribose, phosphate, and a nitrogenous base
7. b. 2
8. e. A-T
9. d. sugar and phosphate
10. e. 6
11. a. hydrogen
12. e. phosphate
13. d. deoxyribose
14. c. hydrogen bond
15. b. base
16. c. 3´
17. e. 5´
18. a. antiparallel
19. c. separated
20. c. phosphates