An Introduction to DNA and Chromosomes

A closer look at what makes up the human genome...

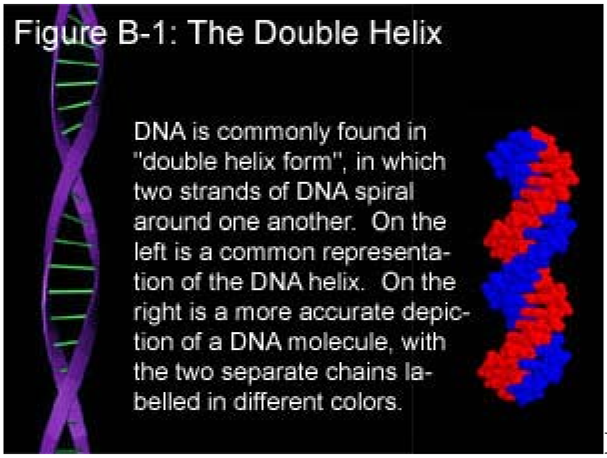
Let's start with the basics of genetics. The word "genome" refers to an organism's complete set of DNA. The fundamental building block of our genome is the molecule known as DNA. You've no doubt heard of DNA many times before – in the news, in movies, on television. Yet in order to understand Huntington's disease, it is important to gain a good understanding of DNA and how DNA is related to genes. Our goal in this section is to review the basic features of the structure and function of the main molecule of heredity.

- What is DNA? ...Making the single strand.
- Why is DNA so important?
- What are complementary strands? ...Making the double helix.
- What are chromosomes?
- OK, so what are homologous chromosomes?

An Introduction to DNA and Chromosomes
Part 1

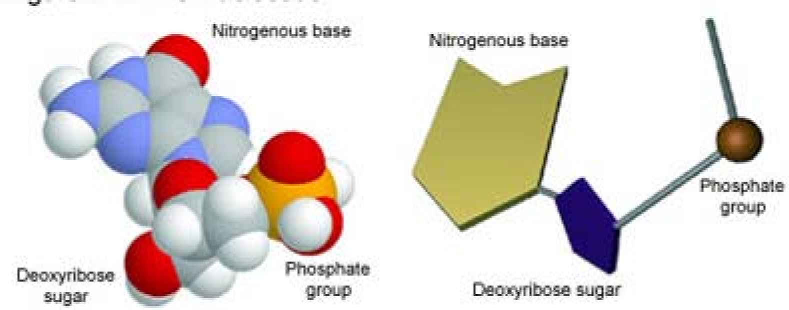
A closer look at what makes up the human genome...

What is DNA? ...Making the single strand.



If you have seen images of DNA before, you probably saw it in a shape or form similar to that shown in Figure B-1. The "double helix" is how DNA is most often found in living cells. In every double helix, there are actually two long strands of DNA; hence, you will often hear scientists refer to a double helix as a double-stranded DNA molecule. As we examine the basic underlying structure of DNA, try to keep in mind the overall arrangement of the double helix; it will help you see how the various components of DNA fit together.

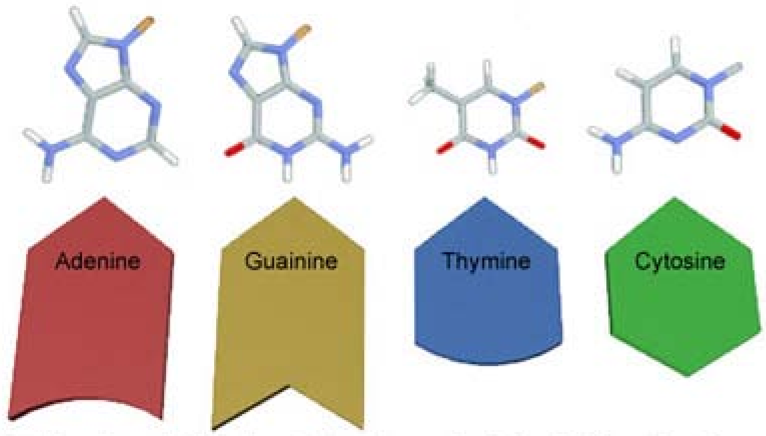
Figure B-2: The Nucleotide



A single nucleotide consists of a nitrogenous base, a deoxyribose sugar, and a phosphate group. Two representations of a nucleotide unit are presented here:
- On the left is a space-filling visualisation of a nucleotide, with the various components labelled. (Spacefill models attempt to approximate as closely as possible the actual spatial dimensions and distances of the molecules. Different elements are represented with different colors: carbon is grey, hydrogen is white, oxygen is red, nitrogen is blue, and phosphate is orange.)
- On the right is a 3D representation of this same nucleotide. (Throughout this text, 3D models will often be used to highlight structural features of DNA molecules. These models are not accurate representations of the shapes and dimensions of the various molecules and should not be taken as such.)

The name DNA stands for deoxyribonucleic acid. By breaking down the name, we can understand the structure of the molecule. DNA is a long string of nucleotide units attached to one another. In a single nucleotide there are three components: 1) a sugar molecule, 2) a phosphate group, and 3) a nitrogenous base. (See Figure B-2.) In DNA, the sugar molecule happens to called deoxyribose, hence the name deoxyribonucleic acid.

Figure B-3: The Four Nitrogenous Bases



Each base has a distinct shape that can be used to distinguish it form the others. 3D representations of the four bases are shown, with the corresponding chemical structures drawn above.

The nitrogenous bases are what make DNA variable. There are 4 different types of bases in DNA: adenine, guanine, thymine, and cytosine. Biologists commonly abbreviate these bases as the letters A, G, T, and C, respectively. (See Figure B-3.) Each one of the bases is chemically distinguishable from the others; as we shall see, it is the variability of these bases that constitutes the genetic code.

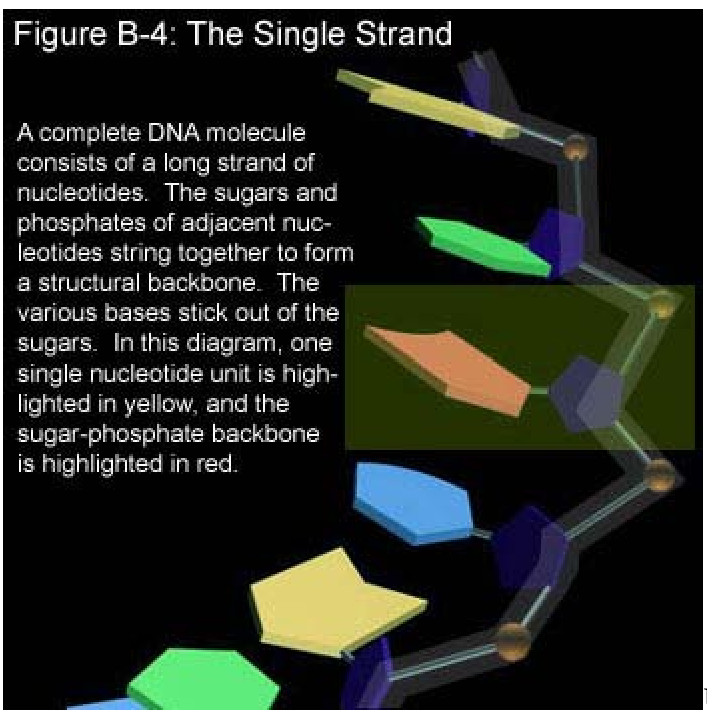


Figure B-4: The Single Strand

A complete DNA molecule consists of a long strand of nucleotides. The sugars and phosphates of adjacent nucleotides string together to form a structural backbone. The various bases stick out of the sugars. In this diagram, one single nucleotide unit is highlighted in yellow, and the sugar-phosphate backbone is highlighted in red.

Unlike the four nitrogenous bases, the sugars and phosphates remain the same throughout the DNA molecule. In a single nucleotide, the sugar is attached at one end to a phosphate group. Because the sugar of that nucleotide can attach to another phosphate at its other end, we can string together many nucleotides in a long chain. This gives us a complete DNA molecule: a structural backbone of deoxyribose sugars linked by phosphate groups, with an orderly sequence of nitrogenous bases sticking out of the sugars toward the middle of the helix. (See Figure B-4.) In terms of our double helix, the single strand provides one-half of the spiraling molecule shown in Figure B-1.

An Introduction to DNA and Chromosomes Part 2

A closer look at what makes up the human genome...

Why is DNA so important?

What makes DNA so exciting to scientists is that it shows how living organisms store information in biological molecules. The structure of DNA is nicely suited to such a task. The structural backbone creates a simple, consistent chain upon which many, many bases can be laid out in an orderly, linear sequence. If we think of these four bases – A, T, G, and C – as the "letters" of a genetic "alphabet," we have the building blocks necessary to encode lots of information within these relatively compact DNA molecules.

DNA therefore shows how living organisms can pass information along to their offspring. DNA tells us how a child can be born with "his mother's eyes," for example, or "his father's nose." For quite some time, scientists had no viable explanation for this phenomenon. No biological molecule was compact yet complex enough to carry the information needed to guide the development of an entire organism. We now know that when a couple have a baby, the DNA of both parents is the crucial ingredient that is passed on to the child. This amazing molecule is thus responsible for the inherited features of every newborn child.

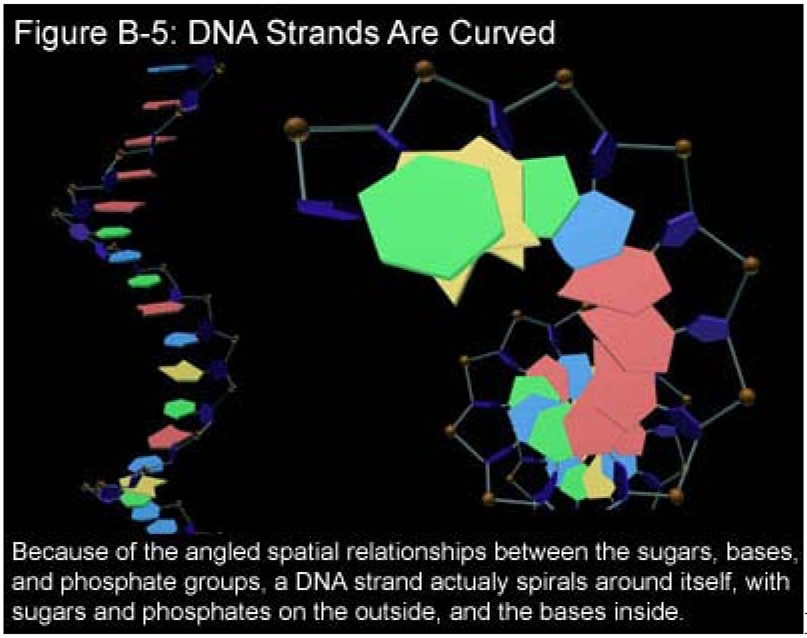
So how can a DNA molecule ever provide enough information for a living organism? The simple answer is that DNA molecules are very, very long. For example, the DNA molecule of a simple bacteria called *E. Coli* is four million nucleotides long. In computer terms, this corresponds to the information-storing capacity of an 8 MB hard drive – quite a bit of memory for a small bacteria! The human genome totals approximately 3 billion nucleotides – a 3 GB hard drive! Thus, we can think of DNA as a "genetic database" for organisms.

An Introduction to DNA and Chromosomes Part 3

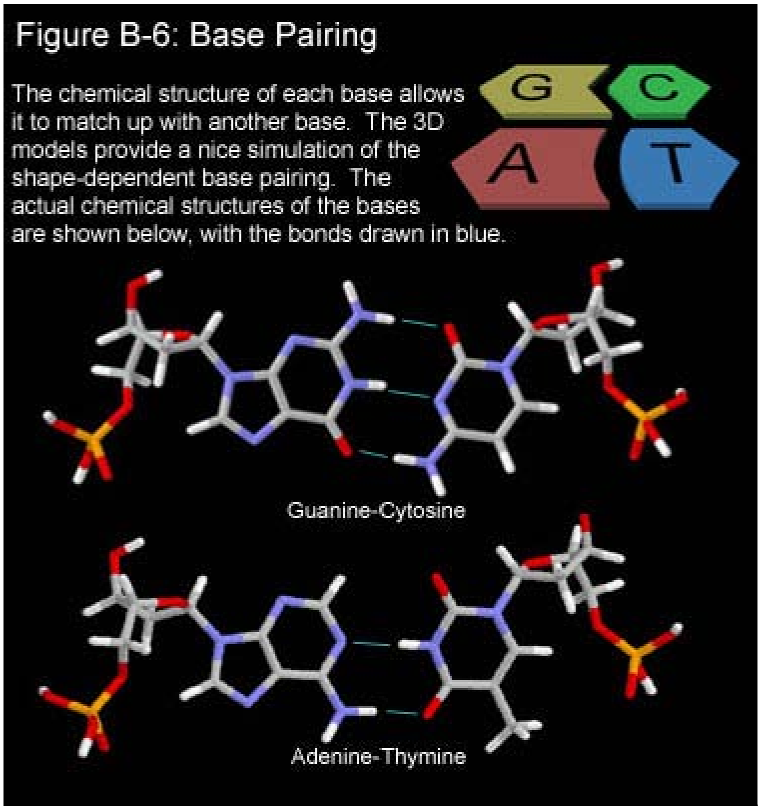
A closer look at what makes up the human genome...

What are complementary strands? ...Making the double helix.

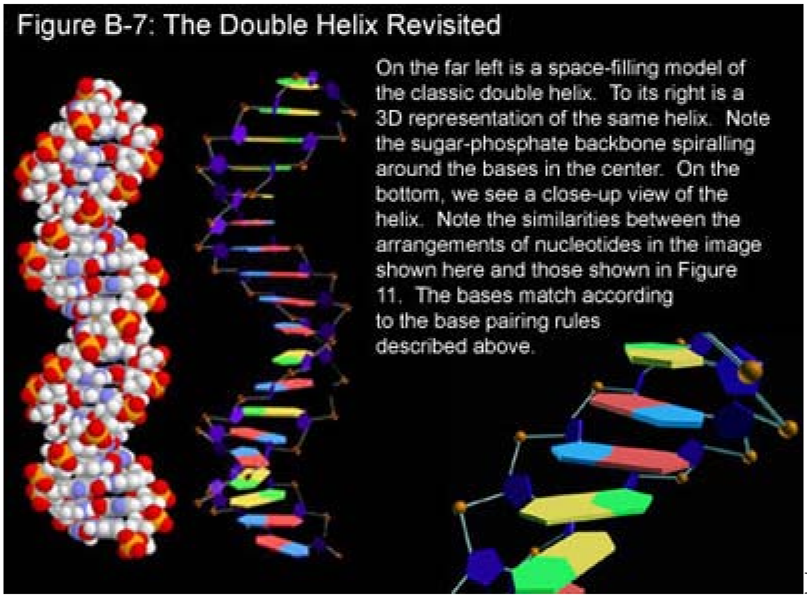
Now that we have a single chain of DNA, we are ready to return to the famous "double helix," in which two single strands of DNA spiral around one another.



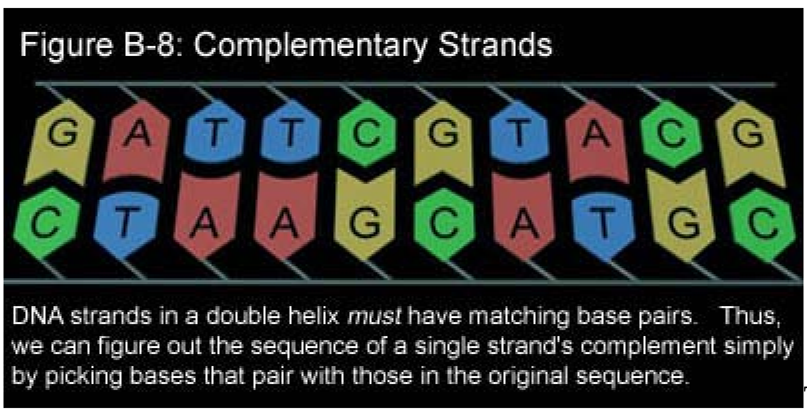
In order to understand the double helix we must first go back to our original DNA strand with its sugar and phosphate backbone. Each connection between a sugar and a phosphate group is at an angle. (Look at Figure B-5 here and compare to Figure B-4 in Part 1 of this section.) The end result is a backbone that is curved rather than straight, and hence the DNA chain spirals around itself. The bases, in turn, jut inward from the backbones, looking almost like the steps of a spiral staircase.



Another important feature of the four bases is that they pair up with one another in a particular way: adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C). Two bases linked up in this fashion are known as "base pairs." Look at the arrangements of the bases in Figure B-6. Notice how the chemical structure of each base allows it to line up perfectly with its pair, but not with any other base. Because of this fact, the two intertwined strands of the DNA helix are said to be complementary.



In summary, a double helix of DNA is composed of two spiraling, complementary strands of DNA. Each strand is composed of a sugar and phosphate backbone with varying nitrogenous bases sticking in towards the center. The two strands are joined together at the center by pairing bases lined up with one another. DNA is often described structurally as a twisting ladder. In this ladder, the “rungs” are the pairs of bases linked together, and the “sides” are the two separate sugar and phosphate backbones. (Examine Figure B-7.)



The double helix is important because it preserves all of the information-carrying features of a single DNA strand while at the same time introducing elements that make it easier for living cells to make copies of their DNA. Because every base pair in the double helix must match its pairing partner (A with T, C with G), we can easily determine the sequence of an unknown strand of DNA if its matching strand is known. For example, if one strand of a double helix has the nucleotide sequence GATTCGTACG, then its complementary strand will be CTAAGCATGC. Figure B-8 shows an example of two complmentary strands.

An Introduction to DNA and Chromosomes
Part 4

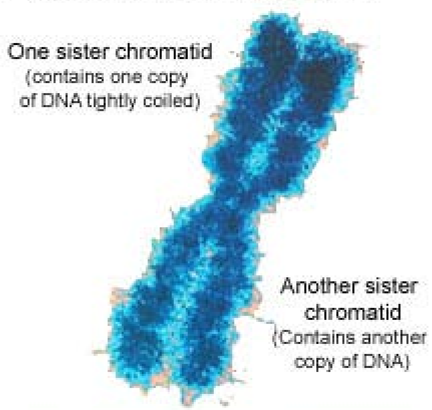
A closer look at what makes up the human genome...

CHROMOSOMES

Having reviewed the chemical basis of heredity in DNA, let us now examine how the "genetic code" is packaged into living cells.

What is a chromosome?

Figure B-9: Chromosome



This picture illustrates the structure of a typical chromosome. The DNA coils tightly so that it can be more easily moved around inside the dividing cell. The two chromatids are joined at the center. Note that the two chromatids are exact copies of each other.

As you might have guessed, chromosomes (Figure B-9) are indeed bundles of DNA. However, in most cells they are present only for a brief moment. In fact, most of the time DNA is spread out in a large, diffuse mass – something like a big plate of spaghetti. When a cell needs to produce more cells, it does so by dividing in two. Think of the problems that this "spaghetti" might cause during cell division, when a dividing cell must bestow each of its successor cells with its own complete set of DNA. Imagine trying to separate and transport a tangled mass of noodles! For this reason, the DNA condenses before cell division into the thick, rod-like form that we recognize as chromosomes.

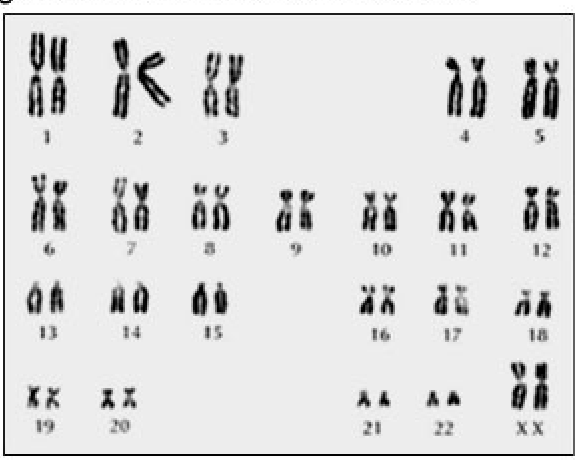
Chromosomes have several important features. First of all, the DNA packs so tightly that one can see it under a simple light microscope. Secondly, recall that because the cell is getting ready to divide in two, the DNA of a visible chromosome has already been duplicated, so that each successor cell will have its own copy. This means that, on close inspection, a cell that is ready to divide will have four strands of DNA, two helices of two strands each. Each of these double strands of DNA condenses into a single rod called a sister chromatid (as in Figure B-9). The two chromatids are therefore exact replicas of one another, and the center of each is joined together prior to the division of the cell. As a result, most chromosomes take on the appearance of the letter X.

An Introduction to DNA and Chromosomes
Part 5

A closer look at what makes up the human genome...

OK, so what are homologous chromosomes?

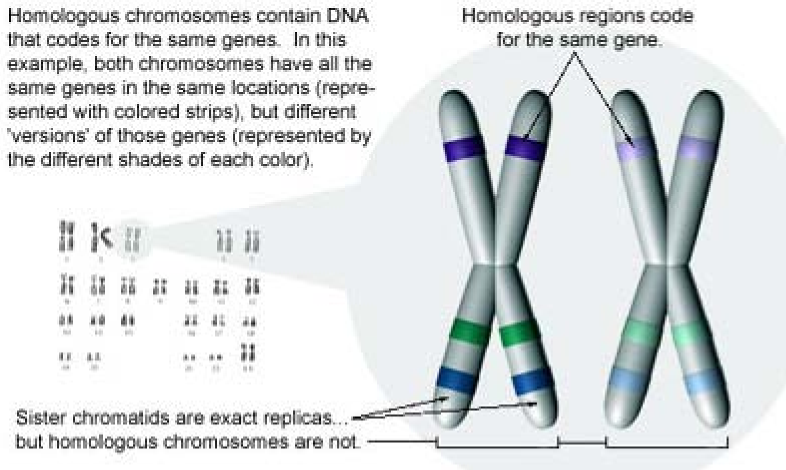
Figure B-10: The Human Genome



A person's 23 chromosomes, when all lined up, might look something like this. Each number in the diagram labels two copies of each chromosome: one from the father and one from the mother. Note that chromosome 23 (the sex chromosome) is labelled with two X's. This particular sample of DNA thus comes from a female.

The human genome (Figure B-10) is composed of 23 kinds of chromosomes. However, because humans conceive through sexual reproduction, every child receives two sets of 23 chromosomes – one from his or her mother and one from his or her father. As a result, every individual has 23 pairs of chromosomes, for a total of 46. Of these 23 pairs, one pair is responsible for determining sex. The chromosomes in this pair are therefore called sex chromosomes. The chromosomes in the remaining 22 pairs are called autosomes.

Figure B-11: Homologous Chromosomes



The two chromosomes in a pair of autosomes are called homologues, or a "homologous pair," meaning that they contain corresponding sequences of DNA (Figure B-11). These two chromosomes come from separate parents. Don't be misled; homologous chromosomes contain DNA sequences that are similar, but they are not identical copies of each other!

-S. Fu, 8-04-01

To learn more about DNA, a number of resources exist on the web:

1. Visit The Tech for a good tutorial loaded with pictures.
2. Australia's "Cooperative Research Centre for Discovery of Genes for Common Human Diseases" (Gene CRC) web site has some fabulous tutorials at various levels of understanding. Visit their "Learning Center" for a general tutorial on DNA. They also have a "Kids Only" section for children.