DNA

WHAT IS DNA?

If you have seen images of DNA before, you probably saw it in a shape or form similar to that of a double helix. 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.

WHAT IS THE STRUCTURE OF DNA?

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*** (deoxyribose);
2) ***a phosphate group***;
3) ***a nitrogenous base***.

The nitrogenous bases are what make DNA variable. There are 4 different types of bases in DNA:

- **adenine** (A)
- **guanine** (G)
- **thymine** (T)
- **cytosine** (C)

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**.

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. In terms of our double helix, the single strand provides one-half of the spiralling molecule.

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 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 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."

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. **We can think of DNA as a "genetic database" for organisms**.

WHAT ARE COMPLEMENTARY STRANDS? ...MAKING THE DOUBLE HELIX.

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. 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.

The four bases pair up with one another in a particular way: **adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C**).

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 centre. The two strands are joined together at the centre by pairing bases lined up with one another.

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.

WHAT IS A CHROMOSOME?

Chromosomes are bundles of DNA.

Most of the time DNA is spread out in a large, diffuse mass. When a cell needs to produce more cells, it does so by dividing in two. Before cell division, the DNA condenses into the thick, rod-like form that we recognize as **chromosomes**.

Chromosomes have several important features:

- The DNA packs so tightly that one can see it under a simple light microscope.
- 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**. The two chromatids are therefore exact replicas of one another, and the centre 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**.

HOW IS DNA PASSED ON TO NEW CELLS?

In earlier sections, we have seen that DNA is a molecule found in living cells that contains the chemical code of heredity. Because all cells, whether they are nerve cells, muscle cells, skin cells, etc., have the same DNA, all of this **DNA must be passed on when cells replicate during the process of cell division**.

Cells start dividing from the time a **zygote** is formed (the single cell that results from the fusion of egg and sperm in animals, or from pollen and ova in plants), allowing it to develop and grow. Most of the cells in our body undergo a type of division called **mitosis**, in which one cell fully replicates its DNA and then divides into two identical daughter cells.

Mitosis consists of several programmed stages. The stage in which the cell spends the most time, while it is between divisions, is named **interphase**. During interphase, DNA replicates and the cell synthesizes proteins that it will need for the other stages. You can think of interphase as the preparatory stage of mitosis.

The first stage of division is called **prophase**. During prophase, DNA condenses into tightly coiled chromosomes. Because DNA has already replicated, each chromosome appears as a joined pair of identical sister chromatids, forming the X shape. Another important part of this stage is the **formation of the mitotic spindle**, a structure that will be responsible for physically separating the sister chromatids into the two daughter cells. It consists of two organizing structures called **centrosomes** (one of which was replicated during interphase) and a set of **microtubules**. Think of the microtubules as tiny fibrous strings that will be used to pull the sister chromatids apart.

In the next stage, **prometaphase**, each centrosome arrives at opposite poles of the cell. Each centrosome has its own set of microtubules that extend out across the cell. Also during prometaphase, the **nuclear membrane** (which separates the nucleus from the rest of the cell) breaks down, allowing the chromosomes to move freely. Microtubules then attach to the centres of the chromosomes, where the sister chromatids are joined, and guide them toward the equator of the cell.

The cell has reached **metaphase** when each of the chromosomes is attached to two microtubules, one on each side, and are lined up in one long row across the middle of the cell.

In **anaphase**, the two centrosomes move further apart and the microtubules shorten. These changes pull the pairs of sister chromatids apart. The newly separated chromosomes can then be sorted into two groups.

During **telophase**, the chromosomes arrive at the centrosomes, and a new nuclear membrane forms around each group, creating two complete nuclei. Inside, the chromosomes begin to **decondense**. Also during telophase, the equator of the cell begins to be pinched by a contractile ring.

The final step of mitosis is **cytokinesis**. During cytokinesis, the contractile ring divides the cytoplasm, or the contents of the cell, in two. **The result is two complete daughter cells, each containing DNA that is identical to the original parent cell**.

HOW IS DNA PASSED ON TO THE NEXT GENERATION?

When humans reproduce, they pass on their genetic information to their offspring. However, if each parent passed on his or her entire genetic code, their child would have twice as many chromosomes as each parent. If this pattern were to continue, the number of chromosomes would double each and every generation, which would quickly become unworkable for cells. **In order for a baby to have a non-increasing number of chromosomes, he or she must receive half the normal number of chromosomes from each parent**.

Therefore, the reproductive cells known as eggs in adult females and sperm in adult males (collectively termed **germ cells**) must have only half the normal number of chromosomes. Hence, **gametes** have only 23 chromosomes instead of 23 pairs (46 chromosomes total) like the rest of the cells in our body. These cells are called **haploid**, as opposed to cells with two pairs of each chromosome that are called **diploid**.

A special kind of cell division called **meiosis** generates haploid gametes from diploid parental cells. Meiosis occurs only for the formation of eggs and sperm, but it is clearly a very important process. **To get daughter cells with half the number of chromosomes, cells replicate their DNA and then divide twice, instead of once as in mitosis**. The result is four daughter cells that are normally genetically different from the parent cell and from each other.

WHAT IS GENETIC VARIATION, AND WHY IS IT IMPORTANT?

Each of the four daughter cells resulting from meiosis is unique. Unlike the daughter cells resulting from mitosis, the products of meiosis are not identical to each other or to the parent cell.

By creating distinctive germ cells each with only one chromosome of each kind (remember this is called **haploid**) the genetic information of the parent cell is reshuffled.

Each daughter cell receives a random mixture of maternal and paternal chromosomes, which leads to **a huge number of possible combinations.**

WHY IS VARIATION IMPORTANT?

Geneticists generally agree that species, such as humans, that reproduce sexually (and make use of independent assortment and recombination) have a competitive advantage over species that reproduce asexually and basically clone themselves. Sexual reproduction leads to immense **genetic variation**, and therefore immense variation in the individuals that are produced.

Evolutionary theory suggests that when environments are highly variable there is an advantage to producing variable offspring: then it is likely that at least some of the offspring will be able to survive the environmental challenges that arise.

Genetic variation can occur by means other than independent assortment and recombination as well. Mutations, or changes in the genetic code, appear frequently in humans and are an important source of variation.

In conclusion, **genetic variation is crucial to the evolution and survival of all species**. Its advantages to living organisms have encouraged the evolution of complex and elegant processes of chromosome shuffling within dividing cells during the process of meiosis. These same processes also serve to make each of us genetically unique, except in the special case of identical twins.