**DNA** is a macromolecule made of **nucleotides**.

Each human cell carries a complete set of DNA containing about 12.5 billion nucleotides.

The basic structure of a deoxyribonucleotide is a **phosphate group**, a **deoxyribose sugar** and a **nitrogenous base**.

Nucleotides form covalent **phosphodiester bonds** between the sugar of one nucleotide and the phosphate of the next nucleotide.

Human DNA molecules are millions of nucleotides long.
• The DNA backbone is the long, continuous chain of alternating deoxyribose sugars and phosphate groups.

• The phosphates have a negative charge that cause the whole molecule to be very polar.

• The bases stick out from the sugars.

DNA is double-stranded, meaning that each molecule is composed of two strands, each with its own backbone and own set of bases protruding from the sugars.

The bases on each strand are complementary. The two strands are held together by hydrogen bonds between the bases and these bonds will only form between an adenine and a thymine, or a guanine and a cytosine. So each strand predicts the base sequence of the other strand (if you made one strand disappear, you could still figure out the sequence of the other strand).

\[
\begin{align*}
A & \rightarrow T \\
T & \rightarrow A \\
G & \rightarrow C \\
C & \rightarrow G
\end{align*}
\]

These are called base pairs.
• DNA twists into a double helix shape because of the way the atoms interact with one another forming its three dimensional shape.

• If you know how many of any one of the four nucleotides there are in a sample of DNA, you can figure out how of each of the other three nucleotides there are as well.

Try It!
1. If a sample of DNA contains 400 million base pairs, and 30% are thymines, then how many of each of the four nucleotides does it contain?
2. What is the complementary sequence to the following strand of DNA:
   A T G G G C T A C A C G T A G G A C
3. What percentage of each nucleotide makes up the strand above?
4. What percentage of each nucleotide makes up the whole double stranded DNA that matches the strand above?

How the structure of DNA was solved:  
http://www.youtube.com/watch?v=VegLYn_1oCE

DNA in Prokaryotic Cells

• May be linear or circular

• It is contained in the nuclear region (nucleoid) of the cytoplasm because prokaryotes don’t have a nucleus

• May also include short, circular plasmids which play an important role in helping bacteria give and receive copies of genes from other bacteria (this is how antibiotic resistance spreads between different strains of bacteria)

• Bacteria reproduce asexually (the “daughter” bacteria are identical to the “parent” bacteria
DNA in Eukaryotic Cells

- Contained in the **nucleus**
- Always linear, no plasmids
- Cell division occurs via **mitosis**

During **mitosis**, a eukaryotic cell divides into two daughter cells. The DNA is replicated before the cell divides. Each daughter cell receives an identical copy of the DNA.

DNA in Eukaryotic Cells

- Eukaryotic cells have much more DNA than prokaryotic cells (humans about 12 feet of DNA per cell)
- DNA is coiled around **histone** proteins to help pack it into the cell – this is called **chromatin**
- Chromatin is **supercoiled** to help pack it into the nucleus – called **chromosomes**
Chromosomes

• Contain all of the **genes** an organism needs to survive and reproduce
• **Genes** are segments of DNA that specify how to build a **protein**
• Each gene (segment of DNA) is copied using RNA and the copy is “read” by a ribosome that uses the encoded instructions to put amino acids in the correct order (thus building the polypeptide that will become the protein when properly folded and finished)

![Chromosomes diagram](image)

The proteins do most of the work in cells (build, communicate, etc). So if a protein does not work do to a mutation, a genetic disorder may result.

DNA Learning Center: How Much of Our Genes Code for Proteins?
http://www.dnalc.org/resources/3d/09-how-much-dna-codes-for-protein.html

Chromosomes

• **Chromosome maps** are used to show the **locus** (location) of genes on a chromosome

![Chromosome map](image)
Chromosomes

• The human genome

✓ Includes about 30,000 genes packaged into 24 different chromosomes
✓ Each person has 46 chromosomes, 23 from mother and 23 from father
✓ 22 of the pairs are called autosomes – they are homologous (contain the same genes)
✓ The 23rd pair is the “sex chromosomes”
  • Females have two X chromosomes which are homologous
  • Males have an X chromosome and a Y chromosome which are NOT homologous because each of these chromosomes contains a different set of genes

Chromosomes

• The human genome

✓ This type of diagram is called a karyotype
✓ Notice that the chromosomes are ordered and numbered according to their size, largest first and the smallest is the 22nd pair. The sex chromosomes are last since they are a special case.
✓ Each chromosome contains a different set of genes. For example, chromosome 1 has the same set of genes, and you have two copies of this chromosome – one set from mom and one set from dad – but none of the other chromosomes have those same genes.
Chromosomes

**The human genome**

- Sometimes the cells make a mistake during cell division and a cell ends up with too many or too few chromosomes. This is called **Nondisjunction**. When this happens during the production of egg or sperm cells, the resulting fetus usually dies. But in some cases it develops into a baby with a genetic disorder.
- For example, Down Syndrome is a disorder in which a person has three copies of chromosome 21.

**Chromosome Ploidism**

- Cells that have two sets of each chromosome (like most human cells) are said to be **diploid** (di = 2)
- Sex cells that have just one set of each chromosome are said to be **haploid**
  - Human gametes (sex cells) are haploid and form a diploid cell when the sperm fertilizes (fuses with) the egg
- Cells that have three or more sets of chromosomes are **polyploid**
  - 3 sets of chromosomes = triploid
  - 4 sets of chromosomes = tetraploid
  - Strawberries have 8 sets of chromosomes = octoploid
Chromosomes

- **The Y makes the Guy**
  
  ✓ All fetuses start out as females (hence the reason males have nipples)
  
  ✓ The **SRY gene** on the Y chromosome switches on at about 5 weeks of development and, in turn, switches on other genes that cause the fetus to start developing into a male.

Check it out!  
http://www.youtube.com/watch?v=z1Kdoja3hik

Mitosis & the Cell Cycle

The purpose of **mitosis** is to replicate a cell into two genetically identical copies.

- **Growth & Development**  
  (you grow by adding more cells, not because your cells get bigger)

- **Repair worn out or damaged cells**  
  (like when you get an injury)
Mitosis & the Cell Cycle

The cell cycle is carefully controlled to prevent the cell from dividing with mutations or other problems

- **Interphase** - Cell is growing and preparing for mitosis
- **Mitosis** - Cell is dividing *(takes about 60-80 minutes)*

**Prophase**

This is the start of mitosis. The chromatin condenses to form chromosomes and the nuclear envelope dissolves. The mitotic spindle starts to develop from the centrioles which each move to opposite ends (poles) of the cell.

The centrioles are responsible for coordinating the construction and movement of the mitotic spindle fibers.
Metaphase

The identical copies of each chromosome are called **chromatids**.

The mitotic spindle attaches to the **centromeres** of each chromosome. It tugs at them in order to line the chromatids up along the center of the cell.

Anaphase

The **centromeres** separate and the fibers of the mitotic spindle shorten causing the chromatids to pull apart so that one of the identical strands of DNA for each chromosome goes to one side of the cell, and the other moves towards the opposite side of the cell. This will result in each new cell having a full set of chromosomes.
Telophase

The nuclear envelope begins to reassemble around each set of chromosomes. In animal cells, the cell membrane pinches off between each full set of chromosomes, forming two cells (this is called cytokinesis). In plant cells, a cell wall is built between the two forming cells. The wall is called a cell plate while it is being built.

Finally, the DNA strands of the chromosomes relax, forming chromatin. Except for any copying errors (mutations) that may have occurred, the two resulting cells have identical DNA to the original cell.

Interphase

Note that interphase occurs prior to the start of mitosis and is NOT PART OF MITOSIS

**G₁ phase** – the cell grows and makes more organelles. It also does its specific job for its cell type.

**S phase** – the cell continues to do its job but at the same time a copy of all of its DNA is made ("S" stands for synthesis). The two resulting identical copies of each strand of DNA are held together with a centromere.

**G₂ phase** – the cell prepares for mitosis by making a copy of its centriole and by making all of the proteins it will need for mitosis.

**G₀ phase** – the cell enters a long-term or permanent state of not growing or dividing in which it just does its job. Many cells in your body are in a state of G₀ (for example muscle cells and nerve cells remain in this state for your whole life)
DNA Replication

✓ Cells must make a copy their chromosomes (DNA replication) before they divide so that each daughter cell will have a copy

✓ A region of the chromosome remains uncopied (centromere) in order to hold the sister chromatids together
  – Keeps chromatids organized to help make sure each daughter cell gets exactly one copy
  – Nondisjunction is when sister chromatids do not assort correctly and one cell ends up with both copies while the other cell ends up with none (remember that Down Syndrome is caused by this)

DNA Replication

• The process of building new DNA is called DNA Synthesis
  ✓ The DNA bases on each strand act as a template to make a complementary strand
    • Recall that: adenine (A) pairs with thymine (T) and guanine (G) pairs with cytosine (C)
  ✓ The process is semiconservative because each new double-stranded DNA contains one old strand (template strand) and one newly-synthesized complementary strand
DNA Replication

1) An enzyme unwinds the DNA and then another enzyme called **helicase** breaks the hydrogen bonds between the bases exposing both complementary strands.

2) Complementary bases are bonded together by **DNA Polymerase** using each of the original strands as a template – note that both strands are synthesized at the same time.

The result is two identical double-stranded DNA molecules. Each is composed of one of the original strands and a newly synthesized complementary strand.

![DNA Replication Diagram](http://www.dnalc.org/resources/3d/23-dna-unzip.html)

![DNA Replication Diagram](http://www.dnalc.org/resources/3d/01-replication-the-helix.html)

![DNA Replication Diagram](http://www.dnalc.org/resources/3d/03-mechanism-of-replication-basic.html)

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Mutations

- Sometimes the wrong base is inserted into the new DNA by accident. This is called a **mutation**.
- The mutation causes a bubble where the two strands do not complement one another (for example, an A-C or G-T pairing).
- Special enzymes recognize the mutation and call in other enzymes to cut it out and repair that section of the DNA.
- Sometimes mutations are not fixed. This can lead to cancer.
Mitosis & the Cell Cycle

The cell cycle is carefully controlled to prevent the cell from dividing with mutations or other problems.

Checkpoints occur in which enzymes stop the cell cycle until certain conditions are met.

Mitosis & the Cell Cycle

Recall that cells cannot do their job when they are in mitosis because the DNA is condensed. Sometimes cells develop mutations that enable them to keep dividing even when they are not supposed to. Because these cells are constantly dividing, they form tumors (masses of tissues that do not do their job). These “bad” cells can spread to other parts of the body. This is cancer.
Mitosis in animal cell: Whitefish blastula

- Interphase
- Prophase
- Metaphase
- Metaphase
- Anaphase
- Telophase, cytokinesis

Extra Photo 06.09.14
Telophase and cytokinesis in animal cells

Telophase in plant cells
Practice Questions

- What is the difference between chromatin and chromosomes?
- Why must a copy of DNA be made? Why does it happen during interphase and not during mitosis?
- What is the role of the centromere? (What would happen without it?)
- What is the difference between a chromatid and a chromosome?
- What events must happen in order for two sister chromatids to separate from one another and move to opposite sides of the cell? (What happens at the centromere? What is the role of the mitotic spindle?)
- What would happen if two sister chromatids moved to the same side of the cell?
- What happens to the mitotic spindle and the centrioles after mitosis?

- What is the difference between chromatin and chromosomes?
• What is the role of the **centromere**? (What would happen without it?)

• What is the difference between a **chromatid** and a **chromosome**?
• What events must happen in order for two sister chromatids to separate from one another and move to opposite sides of the cell?
• What happens at the centromere?
• What happens to the centromere?
• What is the role of the mitotic spindle?

• What would happen if two sister chromatids moved to the same side of the cell?

Nondisjunction

- Trisomy
- Monosomy