The Fundamentals of Biology

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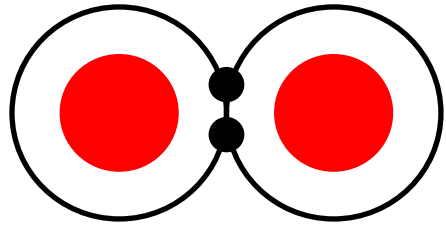
Topic 1.1 Bonds

To begin talking about how life exists, we must talk about chemistry, specifically the elements and compounds that are found in our everyday lives. First, we must know what a bond is and how it can affect the molecules that we see.

Types of Bonds

A **chemical bond** is any interaction that results in an attraction between atoms. There are 3 primary bonds that you should be familiar with: Covalent, Ionic, and Hydrogen. In this section, we will shortly go over each of these, as well as present some simple diagrams.

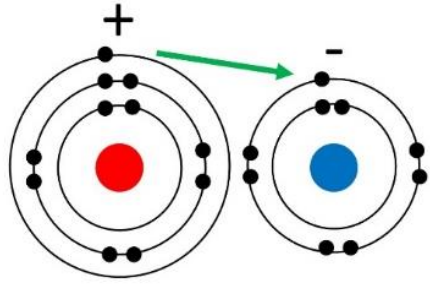
- **Covalent Bond**: The sharing of electrons between two atoms. This can be subdivided into two types:



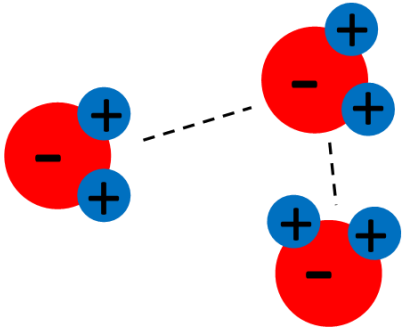
    - **Polar** Covalent: Sharing of electrons is unequal due to differences in **electronegativity**, or the "willingness" of an atom to gain electrons. As a result, there will be positive and negative sides to the molecules. We will see more of this with water.

    - **Nonpolar** Covalent: Sharing between electrons is equal because the electronegativity between the atoms is similar.

- **Ionic Bond:** Electrons from one atom are transferred to another atom, resulting in positive and negative charges of ions.



- **Hydrogen Bond:** Weak bonds that are held between molecules rather than within a molecule.

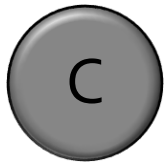


Did you know?

Hydrogen bonds are named for the attachment of Hydrogen to three other elements: Fluorine, Oxygen, and Nitrogen.

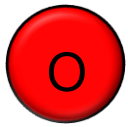
Topic 1.2 Elements of Life

Although there are many elements that exist, there are only a few that are necessary to know for introductory biology. These include carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. Together these elements make up about 97% of humans. Each element will be briefly explained here.



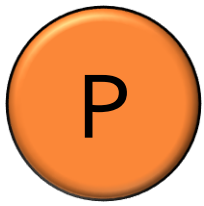
Carbon: The carbon atom can form four total covalent bonds and is contained in all organic matter.

Hydrogen: As the smallest atom out of all the elements, hydrogen is used often in hydrogen bonding.



Oxygen: Used in processes such as respiration and makes up 65% of the human body.

Nitrogen: Found in nucleic acids and proteins, which will be later explained, and makes up a large part of the atmosphere.



Phosphorus: Also found in nucleic acids and is the critical element in the phosphorus cycle.

Sulfur: Occasionally found in proteins.

Quick Tip:

One way to memorize these elements is through the abbreviation CHONPS

Topic 1.3 Water

You might be wondering, *why does water get its own topic?* The reality is water has many unique properties that make it significant to our study of biology. Here is a short list of what makes water so special.

Water's Unique Traits

Cohesion: The attraction of water to itself allows for the beading of water droplets.

Adhesion: The attraction of water onto other polar substances is crucial for biological life. For example, plants rely on adhesion for the upwards movement of water in the xylem.

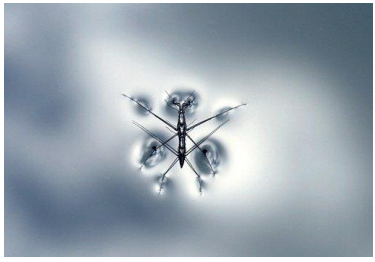
See for yourself!

As you slowly pour droplets onto a penny, you will see that the water will begin to bead up without collapsing. This is due to its cohesive forces!

See for yourself!

As you look at a glass of water, you will notice a meniscus or the upwards rising of water on the edges of the glass. This is due to adhesive forces!

Surface Tension: On the surface of water, there are strong elastic forces that lead to some cool results. For example, some insects like the water strider can walk on the surface of water!



Stable Temperature: Water is relatively resistant to heat change, which explains why the climate in coastal areas varies less than places far from bodies of water.

Expansion from Freezing: While most compounds will shrink when they freeze, water actually expands, making it less dense. This is why solid ice floats on water and explains why bodies of water such as lakes don't freeze completely.

See for yourself!

As you leave a bottle of water in your fridge overnight, you will see that it has expanded!

Universal Solvent: Water is known for its ability to dissolve many solutes.

Topic 1.4 Biomolecules

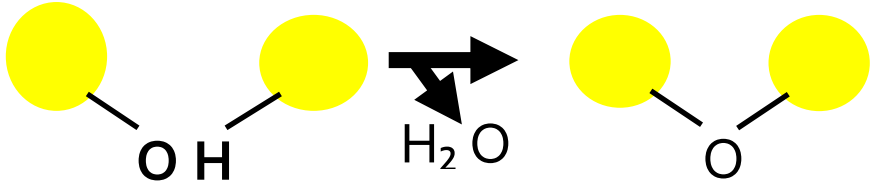
Now that we have a basic understanding of the types of bonds and the elements that are involved with them, we can now discuss the four major biomolecules, those being carbohydrates, lipids, proteins, and nucleic acids.

Introduction

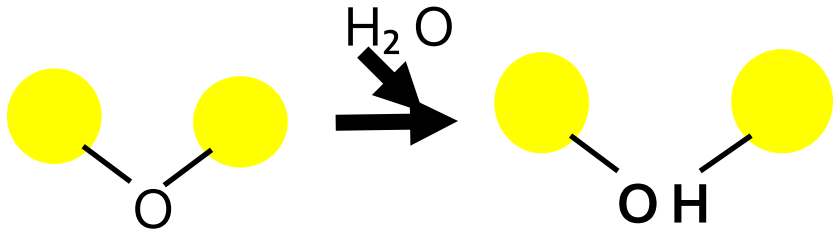
Before we officially start talking about these biomolecules, also known as macromolecules, we have to understand some basic terms.

- **Monomer:** A single molecule with one subunit. Simple enough.
- **Dimer:** A molecule made up of two subunits.
- **Polymer:** A molecule made up of many subunits.

Now, there has to be some way for these subunits to combine and break apart. Luckily, **dehydration synthesis** is the process in which water is removed when building a molecule.



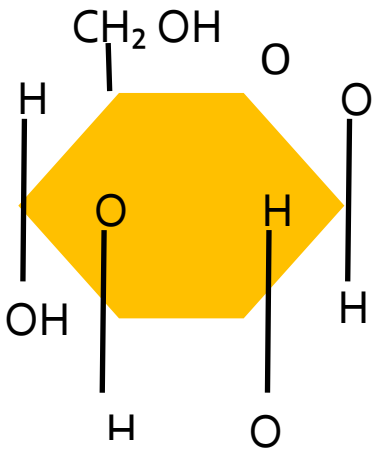
The opposite of this process is known as **Hydrolysis**, where water is used to break two monomers apart.



Now that we have a basic understanding of how these biomolecules are created, we can finally start talking about the first one: Carbohydrates.

Carbohydrates:

Carbohydrates, often known to many as sugars, consist of the elements carbon, hydrogen, and oxygen. Their main function is to act as a quick energy source, which we can obtain by eating. Another one of their main functions is structural support, which we will observe later. Since we have already talked about the types of subunits, we can apply them to this biomolecule.



Monomer: The single subunit of a carbohydrate is called a **monosaccharide**. Examples of this are **glucose**, fructose, and galactose. When drawn, they are often seen in a ring structure, such as the hexagonal structure of glucose shown on the right.

Dimer: You can probably predict that two of these monomers combined will form a **disaccharide.** For example, two glucose molecules combined will form fructose. A glucose and fructose molecule will form fructose. Also significant is the type of bond that forms when they are combined. They are known specifically as a **glycosidic linkage**. Remember, in order to have formed that bond, a dehydration synthesis reaction must have occurred.

Polymer: When more than two subunits are combined, they will form a **polysaccharide,** with the function of both energy and storage. Here are some major examples:

- Glycogen: the energy stored by animals
- Starch: the energy stored in plants
- Cellulose: the structural support unit in plants
- Chitin: the structural support unit found in fungi

Did you know?

Many carbohydrates end with the suffix -ose, which, unsurprisingly, indicates sugar.

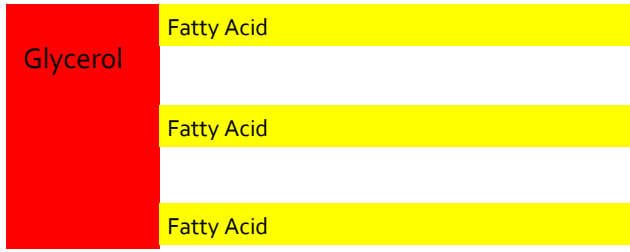
Lipids:

Lipids, also referred to as "fats" and "waxes", are known for their non-polarity. Because of this trait, it does not mix well with water. Like carbohydrates, lipids are composed of the elements carbon, hydrogen, and oxygen, but sometimes will contain phosphorus. Also, like carbohydrates, lipids are used in storing energy, but in this case, it is for long term storage rather than the quick energy from sugars. Other functions include insulation, as well as forming the main component of cell membranes.

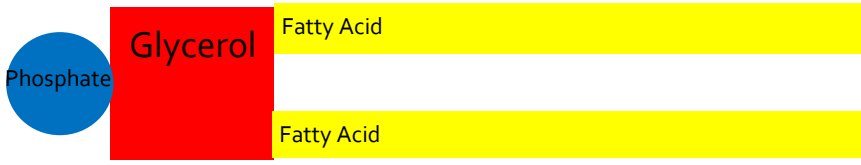
Monomer: Further differentiating lipids from carbohydrates is the fact that its monomer is actually composed of two different parts: the **glycerol** and **fatty acid tails**. Know that the glycerol is a three-carbon chain with oxygen and hydrogen attached, whereas a fatty acid tail is a long chain of connected carbons with hydrogen. When the carbons on a fatty acid tail are all single-bonded, the fatty acid is straight and makes the lipid solid at room temperature. This is a term known as **saturated**, and examples of this include butter and animal fats. On the other hand, if there are any double bonds between the carbons in a fatty acid tail, it will cause a "kink", or a bend in the tail,

making it liquid at room temperature and **unsaturated**. Examples of this include olive and vegetable oils.

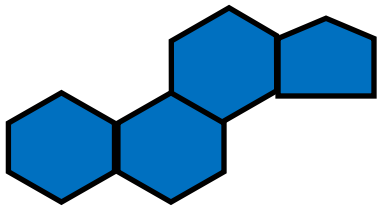
Polymer: When three fatty acid tails are attached to the glycerol by a dehydration synthesis process known as an **Ester Linkage,** it creates a **triglyceride**.



However, there are other types of lipids. For example, when one of the fatty acids is replaced with a phosphate group (just know that it contains a phosphate with elements surrounding it), it creates a **phospholipid**, which is the building block of cell membranes. These are unique because while the phosphate group is polar, the rest of the lipid is nonpolar, giving it unique traits that we will observe later.



The third kind of lipid that should be acknowledged is the **steroid** lipid. This includes cholesterol (which is a component of the cell membrane) as well as hormones that contribute towards gender-driven traits.



Quick Tip:

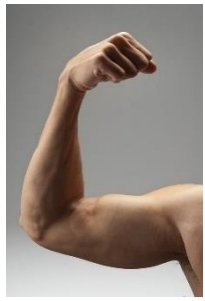
Although you might be inclined to think that steroids are involved with muscles, and thus proteins, remember that they are lipids.

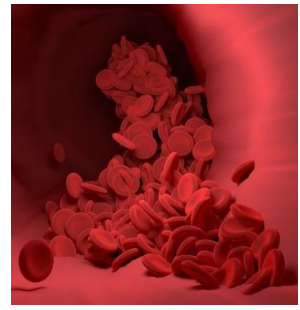
Proteins

We've all heard of proteins. We all know the kinds of foods that have protein (meat, eggs, beans, etc.). But what is the actual structure of this complex macromolecule? Proteins are made up of the elements carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. Proteins have an extremely wide number of uses, some of which we will look at here:

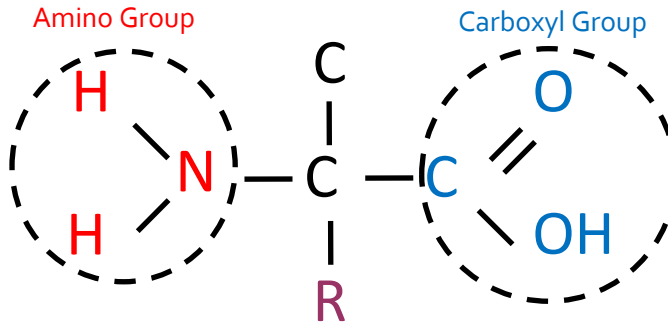
1. Enzymes: These help to speed up chemical reactions are referred to as catalysts.
2. Transportation: As the word suggests, transport proteins such as hemoglobin help to carry substances around the body.

3. Structure: Proteins make up human connective tissues, as well as keratin, the material found in your hair.
4. Defense: Antibodies help to prevent disease.
5. Motion: Muscle fibers help with contraction, and cell movement depends on proteins such as flagella and cilia.





Monomer: The single subunit of a protein is something known as an **amino acid**. These are made up of a central carbon atom with four parts surrounding it: a hydrogen atom, an amino group, a carboxyl group, and finally, an R-group. There are 20 different R-groups possible for a single amino acid, which contributes to the variance we see in proteins.

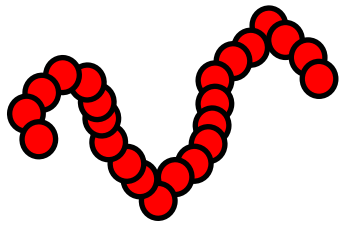


Dimer: Two amino acids are combined with the removal of the OH in the carboxyl group and the H in the amino group to release water and form a **peptide bond**. When they are connected, it creates a **dipeptide**.

Did you know?

A protein's function is highly dependent on many factors such as pH, salt concentrations, and temperature. If a protein is not in its ideal environment, it will **denature**, or unravel, making the protein ineffective.

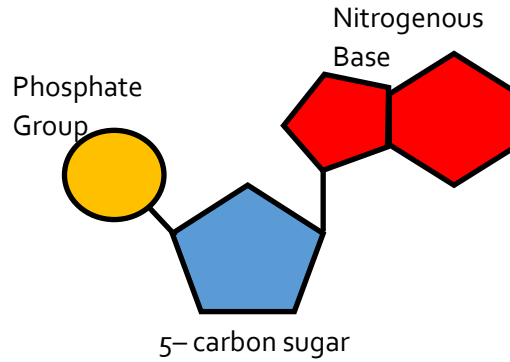
Polymer: When many amino acids are placed together, they form a long chain called a **polypeptide**. It will then fold into three-dimensional shapes to give the protein its specific function.



Nucleic Acids

The fourth and final biomolecules are the nucleic acids. There are two major examples of nucleic acids that you should be aware of: **DNA** and **RNA**. The elements found in nucleic acids are carbon, hydrogen, oxygen, nitrogen, and phosphorus. The main function of these molecules is to provide genetic code for all living organisms of life. It leads to diversity not just between organisms, but within as well. Because it carries out

instruction for making proteins, it is essential for life processes.



Monomer: Its single subunit is called the **nucleotide**. It is composed of three main parts: a phosphate group, a 5-carbon sugar, and one of four nitrogenous bases. In DNA, the nitrogenous base is either adenine, thymine, guanine, or cytosine, which can be simply referred to as A, T, G, and C. On the other hand, RNA can have the same nitrogenous bases, but instead of thymine, it has uracil, meaning its base letters are A, U, G, and C.

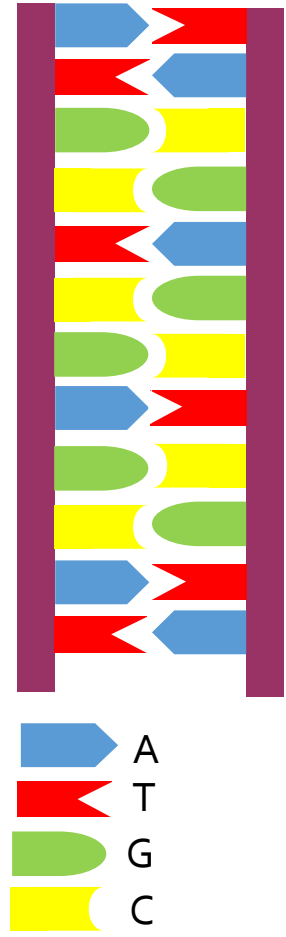
Polymer: When many nucleic acids are put together, they form what we know as DNA and RNA. In both, the phosphate group of one nucleic acid bonds with the 5-carbon sugar of another nucleic acid through a covalent **phosphodiester bond**. In addition, because DNA is double-stranded compared to the single strand of RNA, DNA has weaker hydrogen

Did you know?

DNA stands for Deoxyribonucleic Acid, while RNA stands for Ribonucleic Acid. The deoxy- prefix in DNA is due to a lack of one oxygen in its five-carbon sugar that RNA has the oxygen.

bonds between the nitrogenous bases on both sides of two antiparallel (opposite direction) chains.

Furthermore, there are some rules determining what nitrogenous base that another base can attach to. For DNA, A will always pair with T, while G will always pair with C (In RNA, simply replace the T with a U).



Look at the diagram on the right representing a DNA molecule (if it were RNA, there would only be one long chain instead of the two depicted). To simplify the diagram, the two purple chains represent the sugar-phosphate backbone, and the four colored "blocks" show the four different nitrogenous bases. Note that each base can only pair with one other type of base from the other backbone. The bond between them is the phosphodiester bond as described before.

Quick Tip:

Realize that the model shown on this page is a simplification of the shape of DNA. In reality, the DNA will twist and turn into the double-helix shape that we commonly see when we think of DNA.

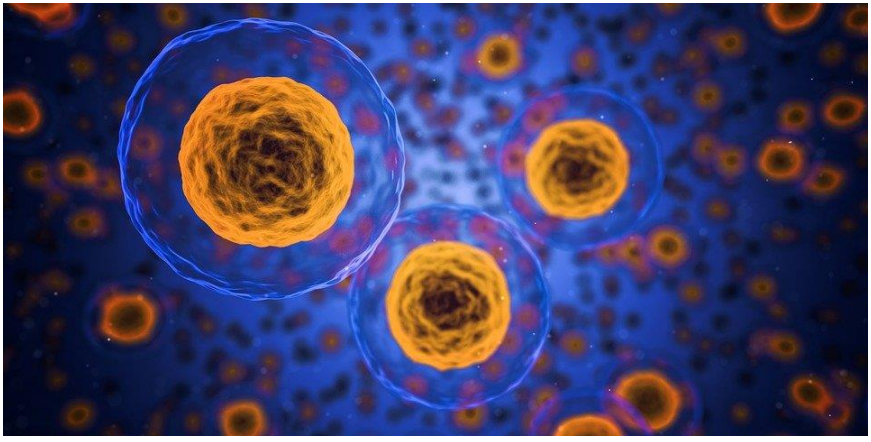
Unit 1 Vocabulary Terms

Adhesion
Amino Acid
Carbohydrate
Carbon
Catalyst
Chemical Bond
Cohesion
Covalent Bond
Dehydration Synthesis
Dimer
Dipeptide
Disaccharide
DNA
Electronegativity
Ester Linkage
Fatty Acid Tail
Glucose
Glycerol
Glycosidic Linkage
Hydrogen
Hydrogen Bond
Hydrolysis
Ionic Bond
Lipids
Monomer
Monosaccharide
Nitrogen
Nonpolar
Nucleotide
Oxygen
Peptide Bond
Phosphodiester Bond
Phospholipid
Phosphorus
Polar
Polymer
Polypeptide
Polysaccharide
Protein
RNA
Saturated
Steroid
Sulfur
Surface Tension
Triglyceride
Unsaturated

UNIT 2: THE CELL

- 2.1 Cell Membrane
- 2.2 Cell Transport
- 2.3 Cell Parts

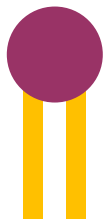
Topic 2.1 Cell Membrane

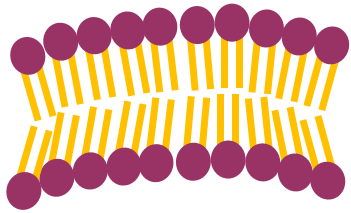


Using our knowledge of biomolecules, we can apply it to the cell, specifically the membrane that encloses all the organelles. In this topic, we will cover the components of the cell membrane, as well as the characteristics it has that allow for transport and exchanging of materials with other cells.

The Phospholipid

Let's begin with the major component of all cell membranes: the phospholipid. Recall that the phospholipid is a type of lipid that has two fatty acid tails and a phosphate group. Due to this, biologists like to simplify the display of the molecule with a circle and two lines. The most significant thing to remember about phospholipids is that they have a polar end on the phosphate side and a nonpolar fatty acid side. Since polar substances are attracted to water, the phosphate side of a phospholipid will face outwards towards the environment. In other words, the heads are **hydrophilic,** "water-loving". However, the water-fearing or **hydrophobic** fatty acid chains will face away from the environment. *Wait, but isn't there fluid on the inside of the cell as well? How does the cell manage that?* The answer is with another layer of phospholipids facing the other direction. The result is a phospholipid **bilayer** that consists of two layers of opposite-facing lipids. Because each lipid can move, it is also referred to as the fluid mosaic model.





Quick Tip:

Although what you see in the model is a 2D segment of a circle, make sure you understand that the cell membrane is a sphere, surrounding the entire cell.

Other Cell Membrane Components

There are other parts of the cell membrane as well:

- Proteins help to move materials in and out of the cell.
- Carbohydrate chains that help cells recognize each other. When a chain is attached to a protein, it is called a **glycoprotein**, whereas chains that are found on the phosphate group of the phospholipid are called **glycolipids.** These are useful in cells that help with the immune response, which will only attack cells that they recognize as dangerous.
- **Cholesterol,** which if you recall is a type of lipid, helps to keep the fluidity of the cell membrane. This is important because temperature changes can cause the membrane to become more or less rigid.

Did you know?

There are both integral proteins and peripheral proteins, with the former crossing through the entire bilayer and the latter only being found on the outer layer.

Transportation of Materials

Now let's go over what can and can't pass through the membrane.

- Small and nonpolar molecules can quickly pass through the membrane without the help of any

protein gates or channels. This includes substances such as oxygen or carbon dioxide.

- Small and polar molecules such as water cannot pass through the cell membrane without the help of a protein called **aquaporin**.
- Large and nonpolar substances like large carbon chains will be able to pass through the membrane, but it will be a slower process than the small molecules, which makes sense because it is more difficult to fit between the phospholipids.
- Large and polar substances like glucose, as well as ions with charges, are unable to pass through the membrane without the assistance of a protein.

As a general trend, things that are nonpolar can more easily pass through the membrane because the lipid bilayer is also nonpolar. Similar to how water will associate with other polar materials due to its own polarity, nonpolar substances will associate with other nonpolar materials.

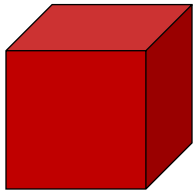
One final thing about cell membranes. Cells tend to want a large amount of cell membrane relative to its size. In other words, a cell wants to maximize the surface area to volume ratio. This is due to the desire of cells to exchange more materials. To accomplish this, cells must be very small. If the volume is too large compared to the surface area of the cell, it will not be able to receive enough resources from the environment.

Side Length: 1 unit

Surface Area: 6 units^2

Volume: 1 unit^3

Ratio: 6:1



Side Length: 2 units

Surface Area: 24 units^2

Volume: 8 unit^3

Ratio: 3:1

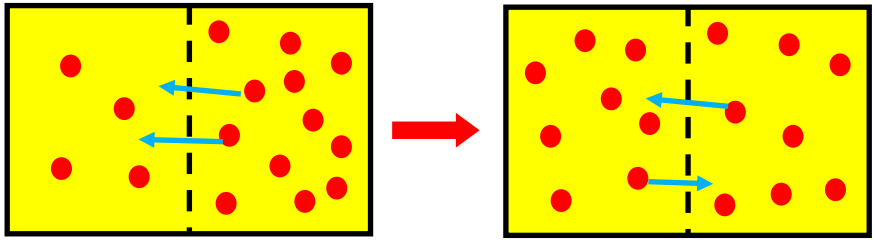
In this simplified model of two different cubes, we can see that the smaller it is, the larger the surface area is relative to its volume. Even though cells are not perfect cubes, they can still be applied.

Topic 2.2 Cell Transport

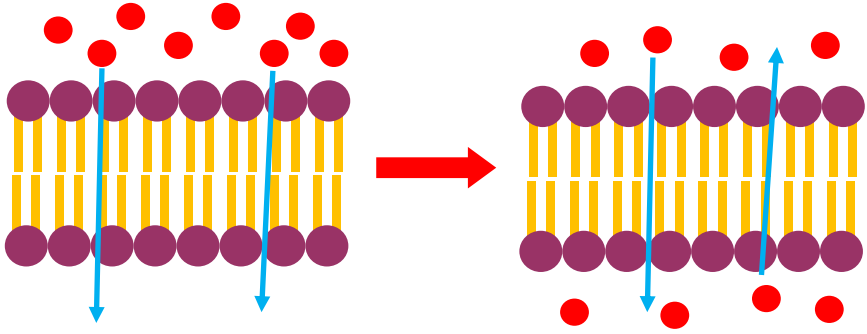
In the previous topic, we briefly went over what could pass through the bilayer. In this next topic, we will go more in-depth on the types of transport that occur in the cell, as well as how the cell maintains equilibrium with its external environment.

Passive Transport

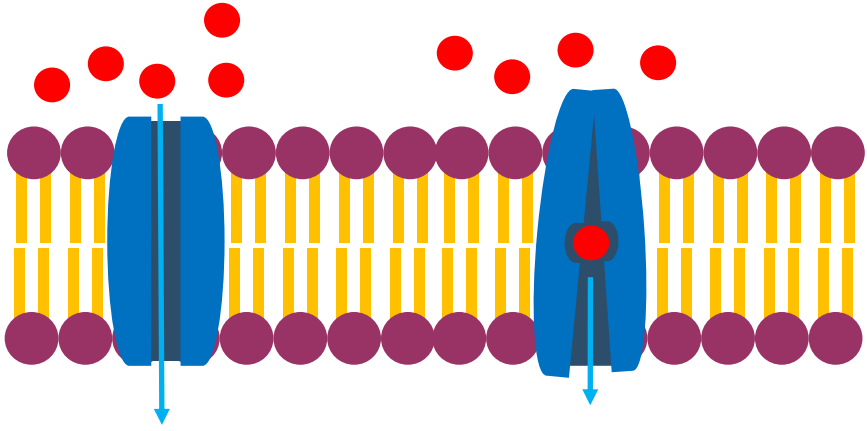
This type of transport is named so because it can occur without energy. This is because particles tend to move "down" their own concentration gradient. What does this mean? We can think of all particles like introverts at a party. They always like to go from a crowded place to a less crowded location. Similarly, when given a choice between two locations, a particle will be inclined to move from a place that is high in concentration to a place that has a low concentration. Therefore, when particles move from a highly concentrated area to a lower concentrated area, it is known as a **concentration gradient**. This passive process will continue until when both locations have an equal concentration, and it becomes known at **equilibrium**. At equilibrium, there is no *net* movement of particles, meaning that although some particles can move from one side to another, the concentrations remain the same. There are three main types of passive transport that are important in the cell: **diffusion**, **facilitated diffusion**, and **osmosis**. We will go more in-depth into them now.



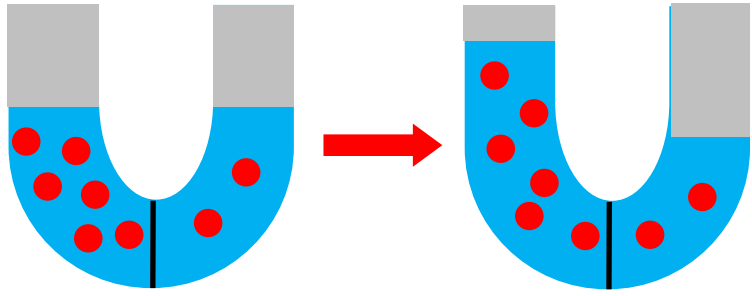
Diffusion, also known as simple diffusion, is simply when molecules go from a higher concentration to a lower concentration by passing through the cell membrane without the help of a protein. It will simply cross the lipid bilayer as explained previously.



Facilitated diffusion is when a protein is actually required to help move the molecules across the membrane. This is used with large polar molecules, as well as charged ions. The proteins that allow for this to occur can either be "channel proteins", which is essentially a tube that lets molecules pass, or a "carrier protein", which will change shapes to allow a specific molecule to move through the membrane.



Osmosis is very similar to diffusion except that it is only the movement of water across the membrane. This is significant because the membrane is **semipermeable,** meaning it allows some molecules to pass while not allowing others. We can describe this more effectively with a U-tube. In this tube, on one side there is a high concentration of a solute, while the other side is low in concentration. You might think that the solute would just move from a high to low concentration. However, in this situation, it is unable to because the barrier in the middle does not allow these large particles to pass. Fortunately, water can move through this "membrane". How will the water move? On the side with high solute concentration, also known as **hypertonic,** there is going to be low water concentration, while on the side with lower solute concentration, or **hypotonic,** there is a high concentration of water. As a result, the water will move from the hypotonic solution to the hypertonic solution until both sides have equally proportioned concentrations.

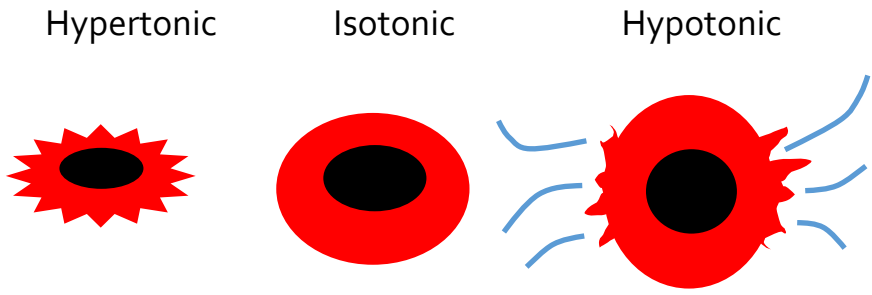


Once this occurs, both sides are **isotonic** to each other.

Returning to the cell, the implications of osmosis can be observed. For example, when cells are placed in a salty environment, salt is unable to pass through the

membrane, leaving water as the only thing that will establish a concentration gradient. Water will move out of the cell since the concentration of water outside is much less than the inside, and the cell will shrink as a result. On the contrary, when a cell is placed in a location that has a lower concentration of salt, the water will move in, causing the cell to swell and sometimes burst, or lyse. Finally, when a cell is placed in a solution that has equal salt concentrations, there will be no net movement of water. Plants and animal cells react differently, however. Plant cells actually prefer to be in a hypotonic solution. This will allow the cell to remain turgid. When it is placed in an isotonic solution, it is flaccid, and when it's in a hypertonic solution it is plasmolyzed. Animal cells, on the other hand, are normal in isotonic conditions.

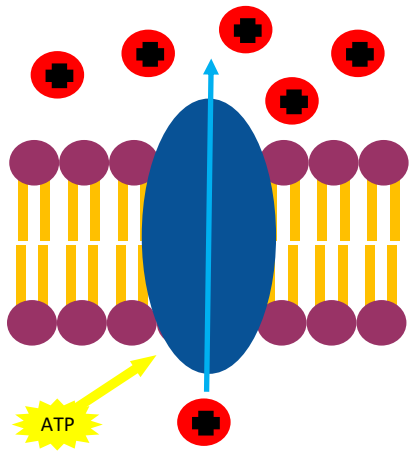
Red Blood Cell in a solution that is:



Active Transport

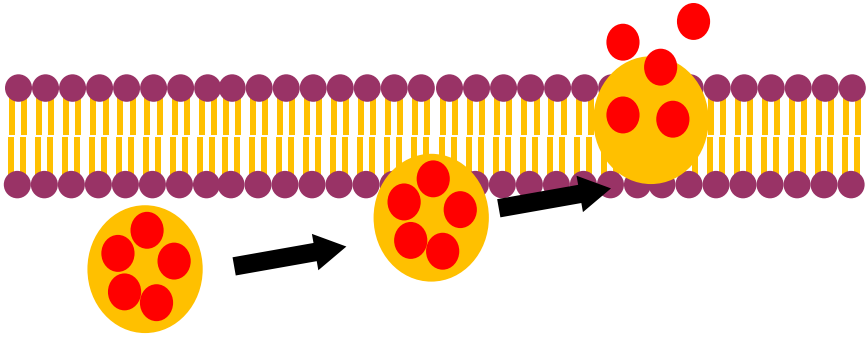
Active transport, contrary to passive transport, requires energy to transport substances because it moves particles from a low concentration to a high concentration. In other words, the particles or molecules will move "up" or "against" their concentration gradient. The three primary types of active transport are the **proton pump**, the **sodium-potassium pump**, and bulk transport.

The proton pump uses ATP to move hydrogen protons (H+) from a low to a high concentration. As a result, the outside of the cell will become positively charged compared to a negative charge inside the cell.

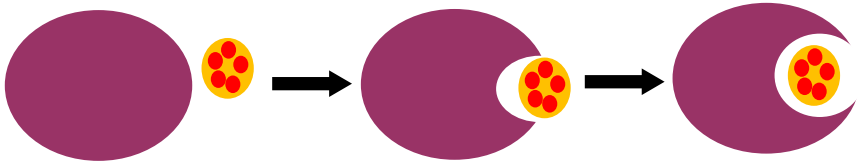


The sodium-potassium pump carries their respective positive ions against their concentration, pumping potassium inside the cell while pumping sodium out. Like the proton pump, it utilizes ATP to move the ions. These are used in the nervous system.

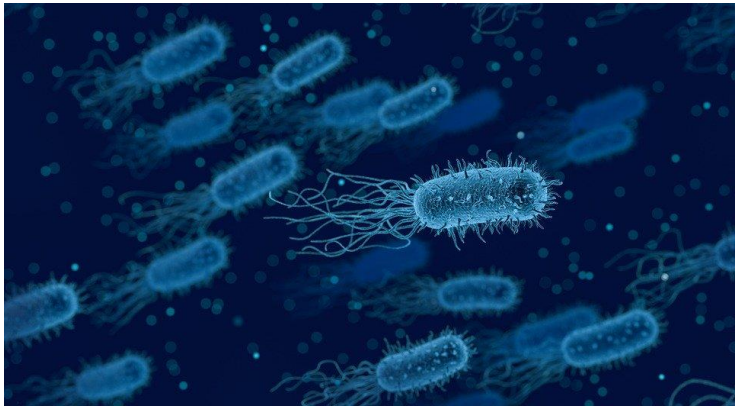
Finally, bulk transport, rather than move ions, transport large substances inside and outside the cell. **Exocytosis** is when the cell packages substances such as wastes and combines with the cell membrane to leave the cell.



Endocytosis, on the other hand, is when large substances enter the cell. Examples of this include **pinocytosis**, which is the taking in of liquids, and **phagocytosis** which is the engulfing of solids. Phagocytosis is prevalent in amoebas to eat.



Topic 2.3 Cell Parts



Although there are some common components within all cells, the large diversity of life means that some cells will have many complex organelles while others will be smaller and more simplistic. We will cover the main similarities and differences in this topic.

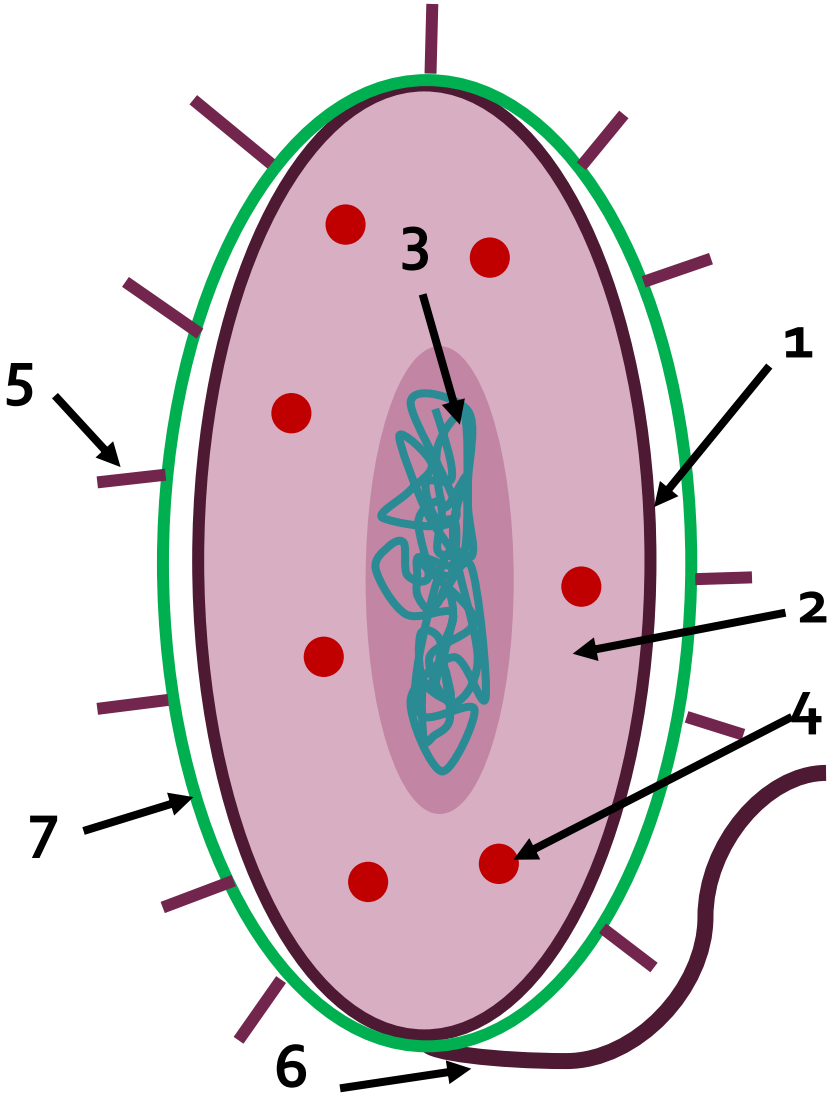
First, we need to cover the major differences between prokaryotes and eukaryotes. **Prokaryotes**, the main cells of organisms such as bacteria, are much smaller than their eukaryotic counterpart and are only found in unicellular organisms. Furthermore, they only have circular DNA, and rather than having DNA located in an enclosed nucleus, it is found in a **nucleoid region**. Most notable about prokaryotes is their lack of membrane-bound organelles.

Quick Tip:

Just because prokaryotes don't have membrane-bound organelles doesn't mean it doesn't have a cell membrane. In fact, not only do prokaryotes have a cell membrane, but they have cell walls as well!

Eukaryotes, on the other hand, are much larger than prokaryotes and have linear DNA located inside of a nucleus. Eukaryotes make up the cells of plants, animals, fungi, and protists, all of which can be multicellular. Contrary to prokaryotes, they do have membrane-bound organelles, allowing for more complex functions. In this book, we will look at the differences between the plant and animal cell, but first, let's present a diagram and explain some parts of a prokaryotic cell.

Diagram of a Prokaryotic Cell



1 **Plasma membrane**- As we discussed earlier, this is the phospholipid bilayer that surrounds the cell. It is semi-permeable, meaning it allows some substances to pass through it while denying others passage. This helps prevent things such as toxic wastes from entering the cell.

2 **Cytosol**- Commonly confused with the **cytoplasm**, the cytosol is only the fluid found inside the cell. This component of the cell isn't an organelle, but rather the location where organelles are located. The cytosol combined with all its organelles is the cytoplasm. The cytosol is where many cell functions take place.

3 DNA- Deoxyribonucleic acid is the place where all the genetic information about the cell is located. The DNA in prokaryotes is circular and tend to be shorter than the linear DNA found in eukaryotic cells.

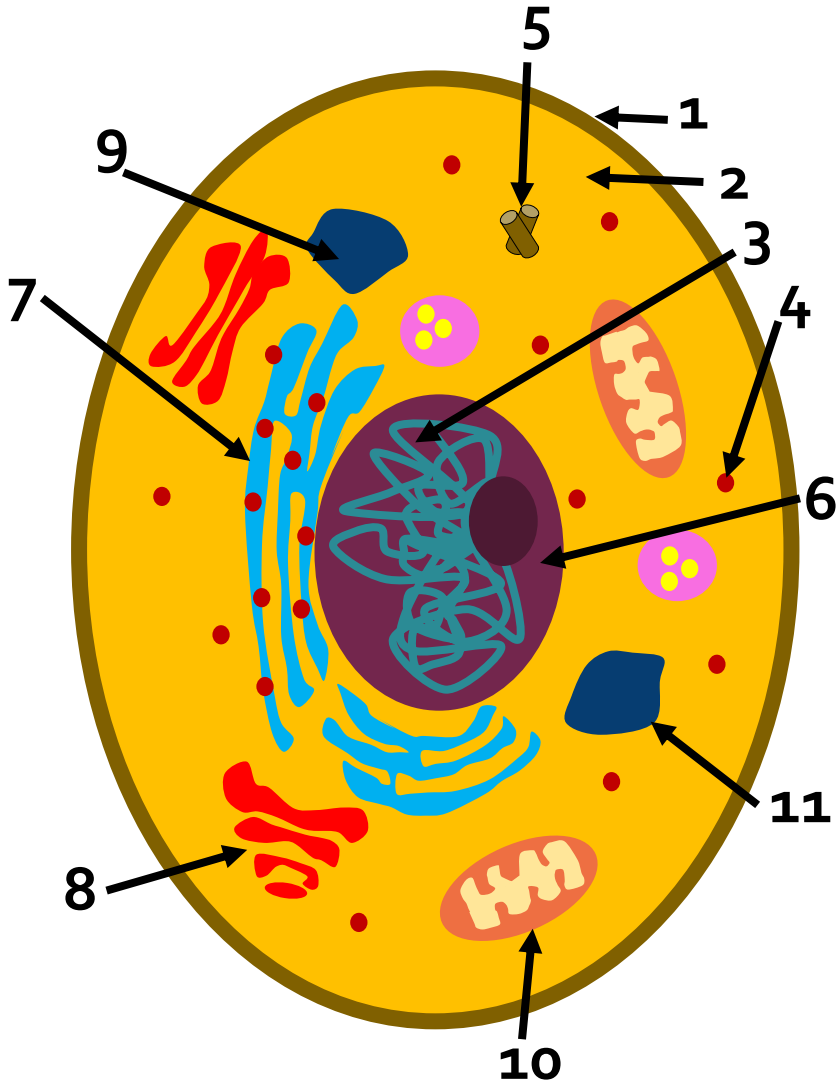
4 **Ribosome**- Ribosomes are the site of protein synthesis, or where proteins are created for molecular functions. They take the genetic code from DNA and create something with it.

5 **Cilia**- These are small protuberances from the cell that gives it the ability to propel itself. These, along with flagellum, assist in cell movement.

6 **Flagella**- This is a long appendage that rotates, allowing bacteria to move.

7 **Cell Wall**- The cell wall is located beyond the cell membrane. It is very sturdy and gives cells a rigid structure. It acts as another layer protecting the cell from extracellular materials.

Diagram of a Eukaryotic Animal Cell



1 Plasma membrane

2 Cytosol

3 DNA

4 Ribosomes

5 **Centrioles**- These are found in the cytoplasm of only animal cells. They are used when cells want to divide, and they form fibers that make up the spindle during cell division, a process we will cover in a later unit. It helps in ensuring that DNA is properly carried over to another cell.

6 **Nucleus**- Primarily known as the "control center" of the cell, the nucleus contains the DNA for creating proteins. Within the nucleus, there are strands of DNA called **chromatin** that provide the instructions for cell processes, as well as the **nucleolus**, which is mostly known for its role in housing the formation of ribosomes.

7 **Endoplasmic Reticulum (ER)**- When the ribosomes are created from the nucleolus, they can freely move to the cytoplasm to aid in protein synthesis or they can attach to a group of folded and flattened discs, creating what is known as the Rough ER. Their job is to transport proteins that are created to other parts of the cell, including the Golgi apparatus. However, if the ER does not have any ribosomes attached to it, it is known as smooth ER, and it has many functions, including detoxifying poisonous materials, storing ions, and creating carbohydrates and lipids.

8 **Golgi Apparatus**- Like the ER, this is another group of flattened membranes that are folded together. Once the proteins reach the Golgi apparatus, also called "Golgi bodies", the proteins are modified and sorted. Know that

for proteins to move around the cell, they must be carried through things known as vesicles. After protein modifications, these vesicles with proteins will travel either to the plasma membrane to be released or remain in the cell.

9 **Vacuole**- While the vacuole in a plant cell is large and central, animals may contain multiple smaller vacuoles. The role of this organelle is to store materials such as proteins and can also keep toxic materials from mixing with other parts of the cell.

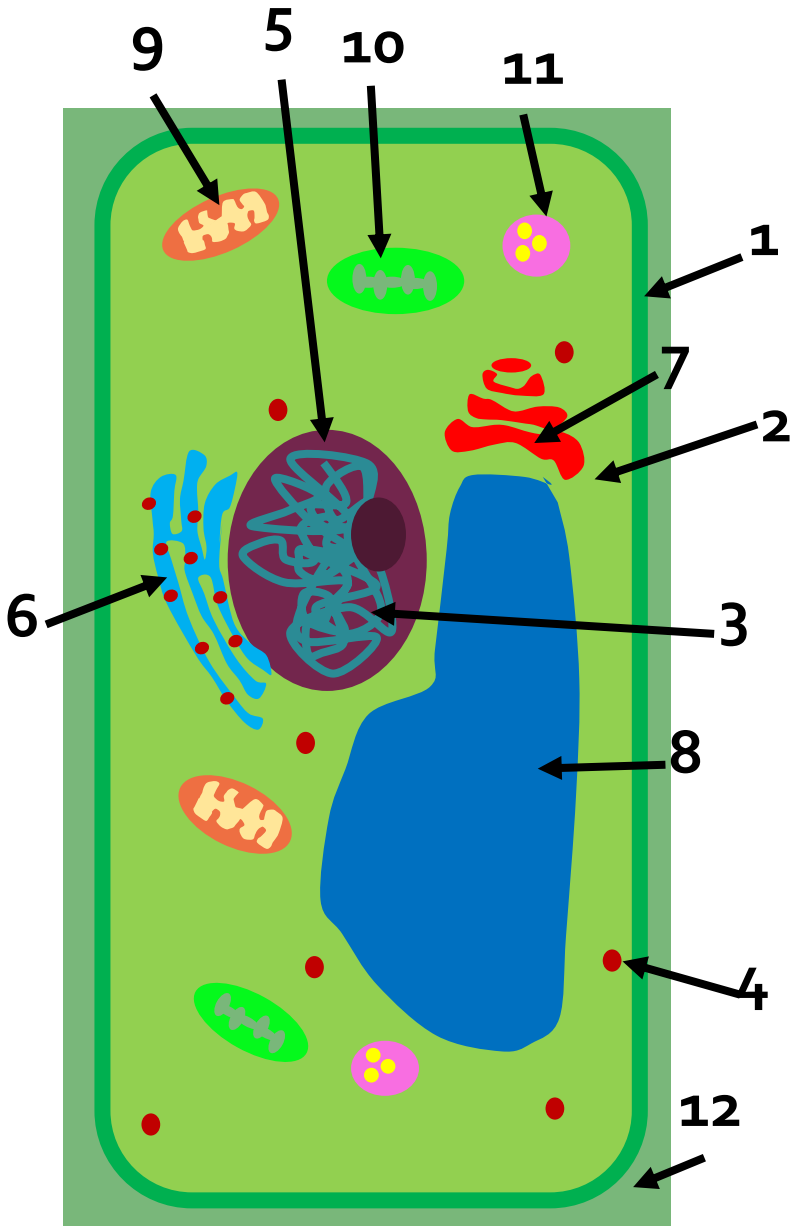
10 **Mitochondria**- You've probably heard the statement that mitochondria are the "powerhouse of the cell". The reason for this is because it is a crucial organelle for the process of cellular respiration, which involves using oxygen and glucose to produce large amounts of ATP, which is the form of energy that all cells require.

11 **Lysosome**- Often referred to as the "trashcan" of the cell, the lysosome can digest materials that are no longer needed by the cell and is also often used in removing toxic wastes from the cell. Furthermore, during phagocytosis, they can take in foreign materials.

Did you know?

Since organelles like the lysosome, mitochondria, ER, and Golgi Apparatus contain membranes that surround it, they are not found within prokaryotic cells, whose cells have no membrane-bound organelles.

Diagram of a Eukaryotic Plant Cell



1 Plasma membrane
2 Cytosol
3 DNA
4 Ribosomes
5 Nucleus
6 ER
7 Golgi Apparatus

Quick Tip:

Plant and animal cells also have flagella and cilia!

8 Central Vacuole- This differs from the vacuoles in the animal cell because in plants, there is only one large vacuole that helps to store materials and especially water.

9 Mitochondria

10 **Chloroplast**- These are unique to plant cells because they are the organelles that carry out photosynthesis or the process of capturing sunlight and using water and carbon dioxide to produce glucose and oxygen as a by-product. Like the mitochondria, the chloroplast has two membranes.

11 Lysosome

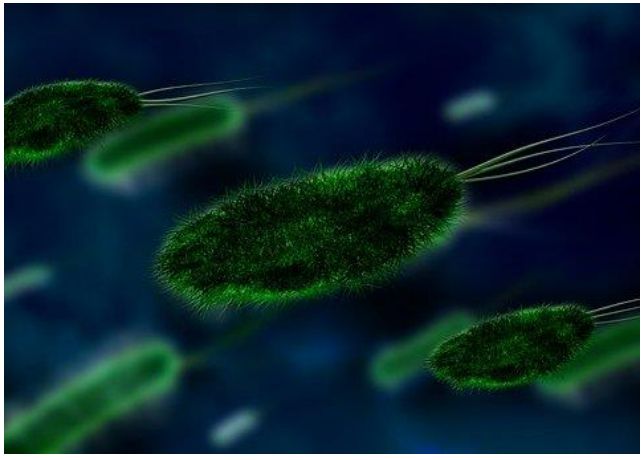
12 Cell Wall

Did you know?

The mitochondria and chloroplast were thought to have been their own prokaryotic cells in the past, one day being absorbed by a larger cell. This idea is known as the endosymbiotic theory.

Although this could not make its own topic, there is one final thing you should know about cells, and that is the **cell theory**. Three main points were discovered by scientists that are still accepted to be true today.

1. Cells are the basic building blocks of all living things.
2. Every living thing in the world is made up of at least one cell.
3. All cells must originate from preexisting cells.



Unit 2 Vocabulary Terms

Aquaporin
Bilayer
Cell Theory
Cell Wall
Centriole
Chloroplast
Cholesterol
Chromatin
Cilia
Concentration Gradient
Cytoplasm
Cytosol
Diffusion
Endocytosis
Endoplasmic Reticulum
Equilibrium
Eukaryote
Exocytosis
Facilitated Diffusion
Flagella
Glycolipid
Glycoprotein
Golgi Apparatus
Hydrophilic
Hydrophobic
Hypertonic
Hypotonic
Isotonic
Lysosome
Mitochondria
Nucleoid Region
Nucleolus
Nucleus
Osmosis
Passive Transport
Phagocytosis
Pinocytosis
Plasma Membrane
Prokaryote
Proton Pump
Ribosome
Semipermeable
Sodium-Potassium Pump
Vacuole

UNIT 3: CELL PROCESSES

- 3.1 Enzymes and Energy
- 3.2 Photosynthesis
- 3.3 Cell Respiration
- 3.4 Cell Cycle

Topic 3.1 Enzymes and Energy

We have already briefly talked about enzymes when talking about the macromolecules, specifically proteins. Now we will go more into depth on what they do and how they can do it.

Energy in Reactions

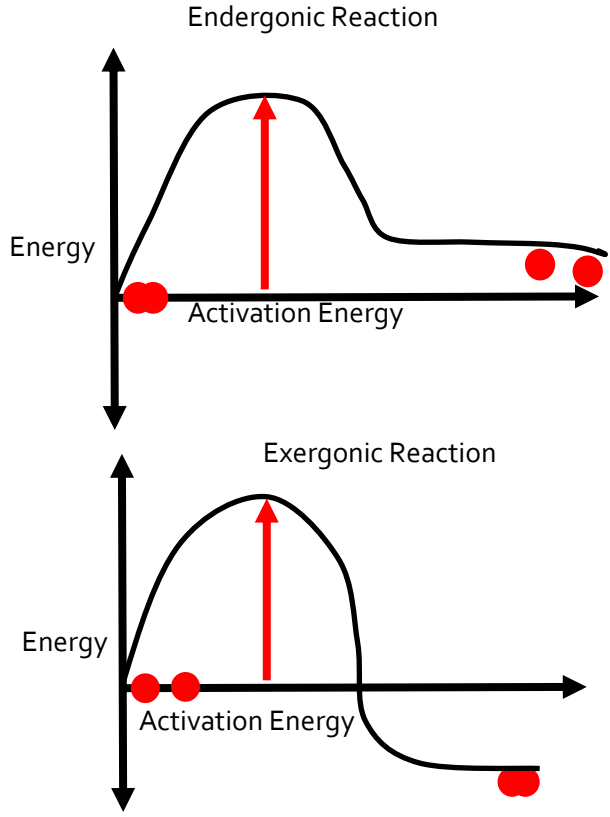
Firstly, we must talk about energy, or the ability to cause matter to change or move. When a chemical reaction occurs, energy will either be released or absorbed. How do we know which one a reaction will cause? Generally, energy is going to be released when chemical bonds are formed, or when the **products** are larger than the **reactants**. As a result, the final energy in the products will be lower than what it started with. Contrary to this, when the reactants are broken down into smaller parts, it will take energy, and the final energy of the products will be higher than before. Two terms associated with these varying processes are **catabolism**, (breaking down) and anabolism (building up). When you consider the net change in reactions, it is referred to as **metabolism.**

Quick Tip:

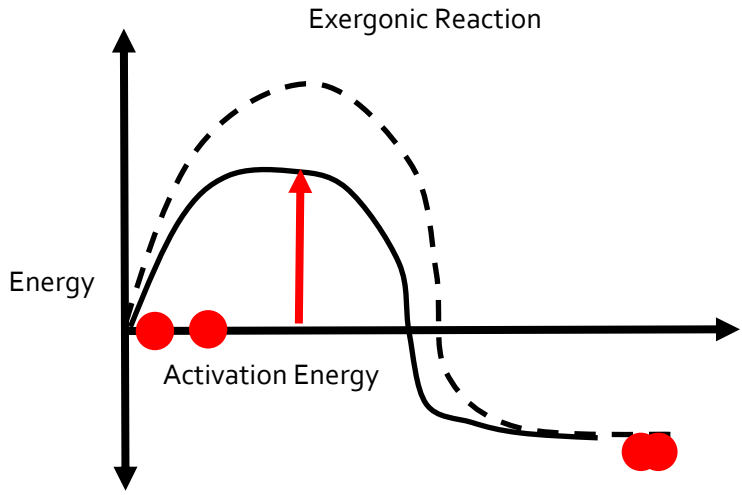
Catabolic reactions are also known as **endergonic** (taking up energy) and anabolic reactions are also called **exergonic** (using up energy)

However, the change in energy is not simply a linear line that goes up if it is breaking apart and down if it's forming. For the reactants of a chemical reaction to actually break or form, it has to reach a certain **activation energy** that is unique to every chemical reaction. In other words, activation energy is the minimum amount of energy that needs to be initially put into a reaction for the

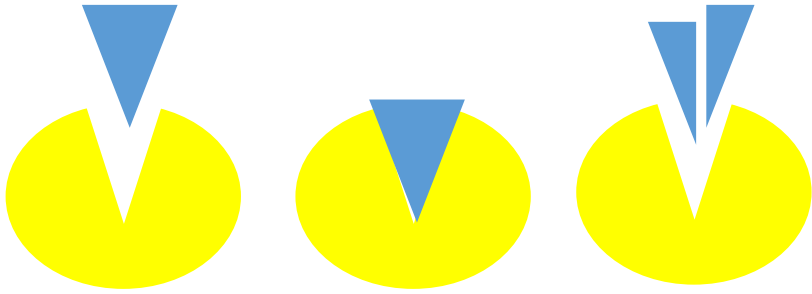
reaction to actually occur. This is commonly represented through this diagram:



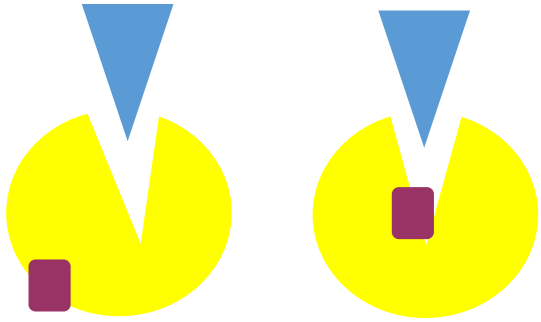
Now that we know what activation energy is, we can finally talk about what enzymes do. We have explained earlier that enzymes are proteins that act as **catalysts**, which speed up the rate of chemical reactions. While this is a simple description of what it does, the reality is that enzymes lower the activation energy required for a reaction to occur. For example, let's refer to the diagram previously shown. Notice the height of the activation energy. However, with the addition of an enzyme, the activation energy is lower:



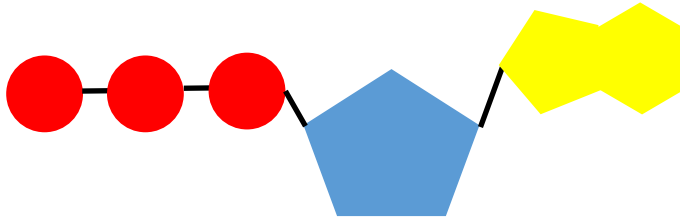
The implication of this is that less energy is needed for the reaction to occur, making it faster and more efficient. So how is an enzyme able to work with the reactants of a chemical reaction and cause the activation energy to be lower? The answer is with the enzyme's **active site**. This is the location that the reactants of a reaction are placed before they are turned into their products. When on the enzyme, the reactant is known as the **substrate**, and together they are referred to as the **enzyme-substrate complex**. The active site must be a specific shape for the reactants, acting like a lock-and-key fit. If the active site cannot fit the substrate, the enzyme would basically be useless. As a result, enzymes are very specific to the types of reactants they can accept. Once the reactants can bind to the enzyme, however, the catalyst will carry out its function, and the product will be released from the enzyme, whether it be a built or broken compound.



There are several ways that an active site can change shapes that cause it to lose its effectiveness. For example, the environment plays a crucial role in the shape of the protein. Enzymes usually are most effective at a certain temperature, salinity, and pH (which measures the acidity of something). Whenever these requirements are not met, enzymes will start to **denature**, or lose their shape. Once this happens, the active site will no longer allow for a substrate to combine with it. Another way this lock and key fit can be disturbed is by inhibitors. These can be a variety of molecules that will either bind to the active site to directly prevent the addition of a substrate (**active inhibitor**) or be placed elsewhere on the enzyme to change the shape of it (**inactive inhibitor**). In both cases, the active site is ineffective.



One final thing about enzymes. They can be reused after a reaction occurs, meaning when the products are freed from the enzyme, they can take up new substrates and repeat the process of lowering the activation energy. This explains why the rate of a chemical reaction is determined by the enzyme concentration. If there are a small number of enzymes in a reaction, then fewer reactants are having their activation energy lowered. However, with more enzyme concentration, more reactants can simultaneously bind to enzymes. Note that if there are more enzymes than reactants, not all the enzymes will be used, and the rate of the reaction cannot speed up beyond that point since all the reactants will be sufficiently sped up with the enzyme. When this happens, it is referred to as **saturated.**



Returning to the idea of energy, the main way that our body can get energy is through **ATP**, or adenosine triphosphate, appropriately named due to its structure having an adenosine base and three phosphate groups attached to a 5-carbon sugar. ATP works by releasing one of its phosphate groups off of it by using a hydrolysis reaction. That single phosphate group will attach to another molecule and make it excited, which is a process called **phosphorylation**. This excitation is the energy that allows for cells to function. For the now adenosine *di*phosphate to gain back its phosphate group, it will use

a dehydration synthesis reaction, making the ATP cycle complete and allowing the renewable energy source to be usable once again. ATP is created from the catabolic reactions and is used up in anabolic ones. This is why photosynthesis, a process that produces ATP to build the larger molecule of glucose, is referred to as endergonic or catabolic, while cellular respiration, which releases ATP for bodily function, is called exergonic or anabolic. In fact, photosynthesis and cellular respiration are known to be opposites of each other, which is clearly highlighted with their reactants and products being opposite of each other.

Photosynthesis and Cellular Respiration are known as **redox** reactions or reduction-oxidation reactions. Here is what that means:

Reduction is the process in which electrons are gained in a process, while **oxidation** is when electrons are lost. This might seem counterintuitive but think about it in terms of charge. If you have more electrons, it will have a more negative charge, so there is a "reduction" in charge.

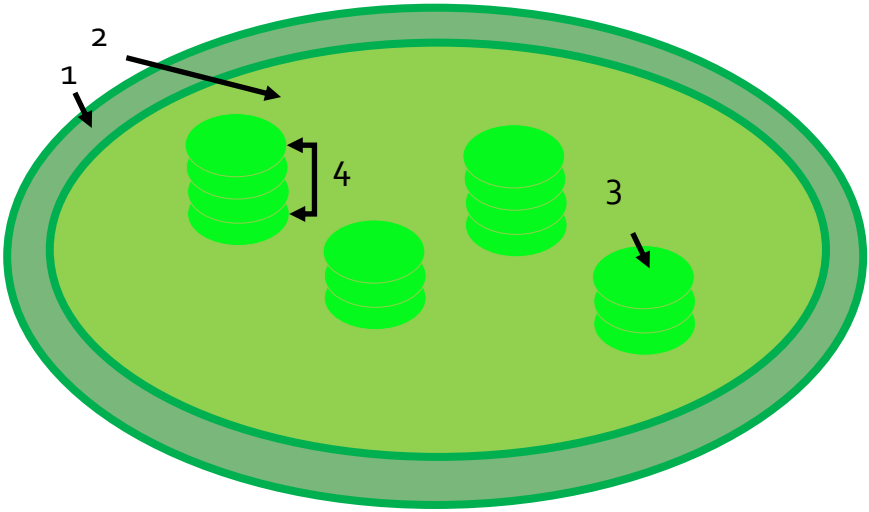
Therefore, a redox reaction means that there is the movement of electrons from one thing to another.

Topic 3.2 Photosynthesis

Photosynthesis is simply known as using light energy to make food for plants. However, the actual process in which plants use energy, water, and carbon dioxide to produce glucose and oxygen can be somewhat complex, so I will try my best to break down the process into steps that are easy to understand.

Introduction

First, we know that photosynthesis occurs in plants. Simple enough. However, did you know that most synthesis actually occurs in the leaf? Specifically, it occurs in the **mesophyll** of the leaf. Here, there are small openings called **stomata** that allow for the exchange of gases such as oxygen and carbon dioxide, which are crucial for the functioning of photosynthesis. On a smaller scale, the place within the cell that photosynthesis occurs is in the **chloroplast**, discussed briefly in the cell organelles topic. Within the chloroplast, there are several parts to be familiar with:



1 The chloroplast has two membranes, an outer one and an inner one. The space between these membranes is called the **intermembrane space**.

2 The stroma is simply the liquid substance found inside the membrane.

3 The **thylakoid membrane** is a sac that contains the green pigment **chlorophyll** which absorbs light energy. The space inside these membranes is the **thylakoid space**.

4 When many thylakoids are stacked on top of each other, they are called a **granum**.

With the parts of the chloroplast out of the way, we can now discuss the process that actually occurs. The official equation for photosynthesis is as follows:

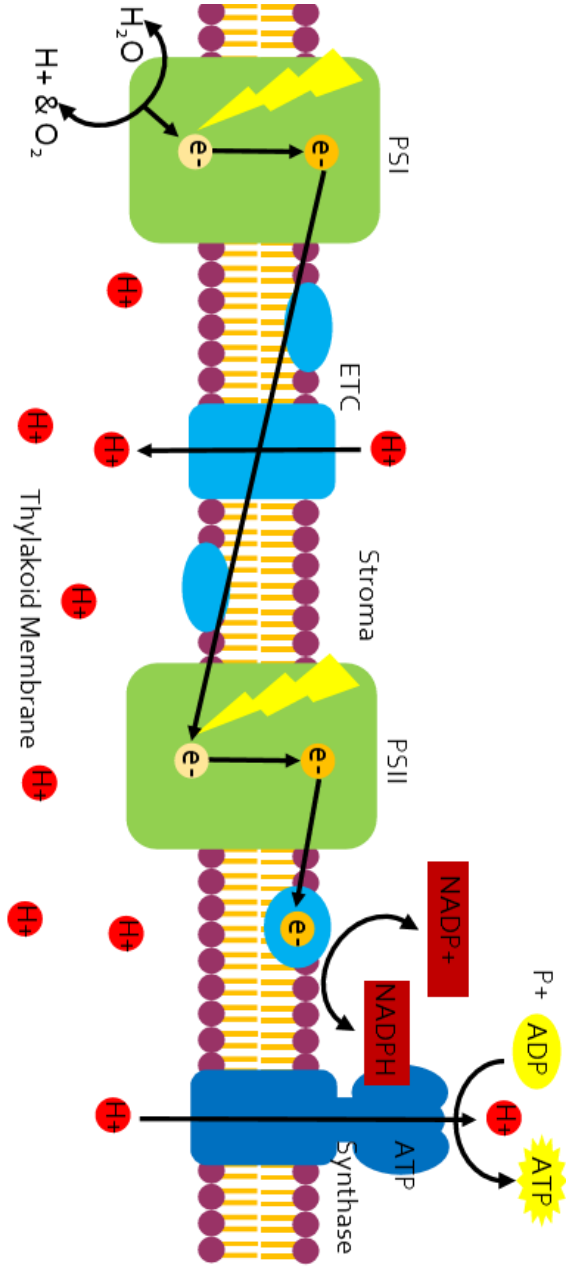
$$6CO_2 + 6H_2O \text{ ---(Light Energy)---> } C_6H_{12}O_6 + 6O_2$$

This might seem like a lot to take in, so we will break down the process into two major "parts": The light-dependent, and the light-independent reactions.

Light -Dependent Reaction

So-called because of the light energy required to function, the **light-dependent** reaction occurs in the thylakoid membranes of the chloroplast. To simply break it down, what it does is convert water into oxygen, and then produce energy that will be used up in the next step. The more complicated steps are as follows:

Light-Dependent Diagram

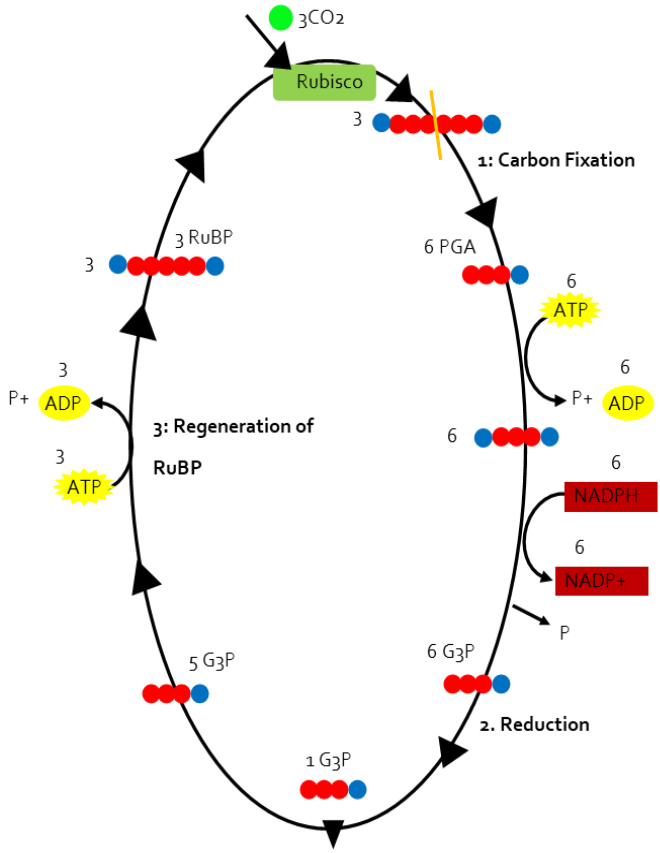


1. Within the thylakoid membranes are photosystems whose role is to take up light energy through small particles called **photons**. This is where chlorophyll is located. In the first step, a photosystem called **Photosystem II** absorbs these photons, and the photons will cause an electron to become excited with energy.
2. Once the electron is excited to a certain extent, it will be caught by the **primary acceptor.**
3. The breakdown of water will replenish this electron that was caught, and since water is H_2O, it will break down into oxygen, which will release into the atmosphere, as well as Hydrogen. Since hydrogen has one electron and one proton, the electrons are used to replace the one that got caught previously and the proton will stay inside the thylakoid space.
4. Electrons will then travel through an **electron transport chain** or the ETC. On this chain, there is a proton pump, which will pump protons that were previously in the stroma into the already concentrated thylakoid space (due to the H+ protons from the breakdown of water).
5. Since protons cannot pass through the thylakoid membrane to get to the thylakoid space by themselves because they are moving up their concentration gradient, they must pass through **ATP synthase**, which will create ATP for the second major step of photosynthesis by using ADP (adenosine diphosphate) and a phosphate group to convert it into adenosine triphosphate.

6. Returning to the electrons, after the ETC, they will reach another photosystem called **Photosystem I,** and the process that happens with Photosystem II repeats.
7. However, instead of being caught by the primary acceptor at the end, it will end up on an electron acceptor known as **NADP+,** which then becomes **NADPH**. The primary function of NADPH is to carry electrons in the form of energy. NADP+ is said to have been reduced since it gained electrons. The NADPH will be used in the second step of photosynthesis.

The Calvin Cycle

The second step of photosynthesis is the light-independent reaction, meaning light is not required in this step for it to actually work. Note that without the light -dependent reactions, the energy created in those steps would not be present during the **Calvin Cycle,** so photosynthesis will always require light energy to work. The job of this cycle is to take carbon dioxide and create glucose. The Calvin Cycle occurs in the stroma of the chloroplast, and can be broken down into three main steps:



1. **Carbon Fixation:** 3 carbon dioxide enters the cycle, and with the help of an enzyme called **rubisco**, will attach to 3 separate molecules called **RuBP**. The structure of RuBP is 5-carbon molecules with two phosphate groups, one on each end. When the carbons are added, it creates 3 molecules of 6-carbon chains with 2 phosphates (a total of 18 carbons). This carbon chain is unstable, however, and all three of them will split in half, forming 6 three-carbon chains with one phosphate group called PGA. The total number of carbons remains 18. Then, using 6 ATP from the light-dependent reactions, a phosphate group will be added to the 6 PGA molecules, exciting them.
2. Reduction: Because the PGAs are excited with the phosphate group, it will release it, which will return to ADP to form ATP and recycle it. While it does that, 6 NADPH electron carriers from the light reactions will carry one electron to the PGA molecules. The result of this is 6 **G3P** molecules, which are three carbons with one phosphate group. The total number of carbon atoms remains 18. However, this will change as one G3P is released to contribute towards the creation of glucose (two G3P are needed to create one glucose, so two cycles of the Calvin Cycle are required for one glucose production). Now the total carbons in the cycle are 15.
3. Regeneration of RuBP. With the 5 remaining G3P molecules, three ATP molecules are used up and rearrange these 15 carbon atoms into 3 molecules

of 5 carbons and two phosphate groups, creating the 3 RuBP that will then combine with carbon dioxide, thus finishing the cycle.

Notice that at the end of the cycle, NADP+ and ADP are produced from it. These will go back to the light reactions where they will once again from NADPH and ATP respectively.

This thus concludes the process of photosynthesis. Although it is composed of many complex steps, the key takeaways from this topic are the main reactants and products of each major step.

Topic 3.3 Cellular Respiration

The opposite process of photosynthesis is cellular respiration. In this chapter, this process will be described, both in the presence of oxygen as well as alternatives when this molecule is not present in the environment.

Introduction

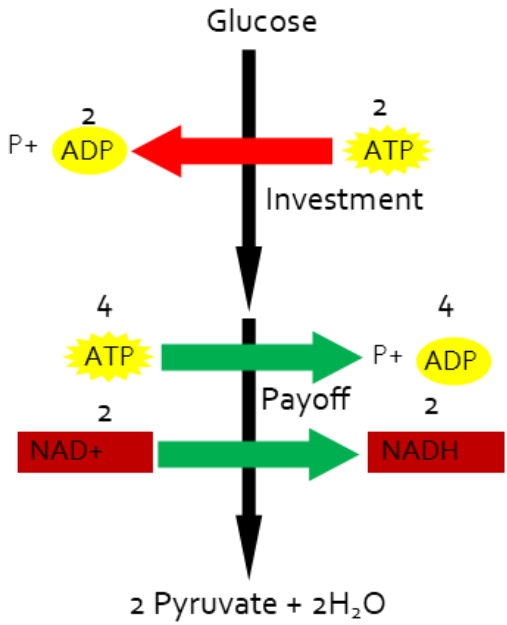
The main steps of Aerobic Respiration, or cellular respiration in the presence of oxygen, occur both outside and inside the mitochondria. Overall, respiration can be split up into three major steps: **Glycolysis**, the **Krebs cycle**, and **Chemiosmosis**. The first step occurs outside of the mitochondria in the cytosol of the cell, the Krebs Cycle occurs in the middle of the mitochondria, called the **matrix**, and Chemiosmosis occurs between the two membranes in the mitochondria or the intermembrane space. The equation of cellular respiration is as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

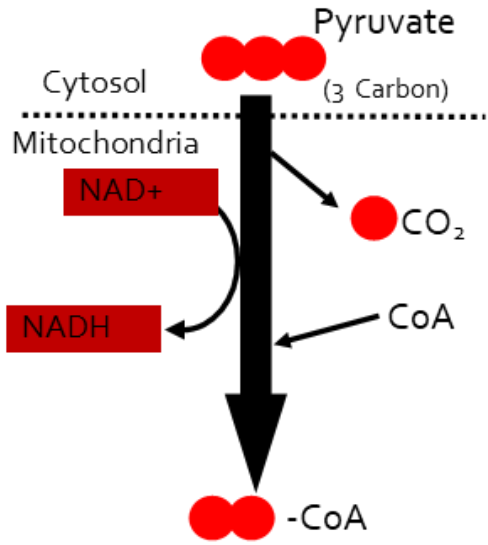
However, this is not the full story. As you may know, the purpose of cellular respiration is to provide energy in the form of ATP. The creation of this ATP is reliant on the presence of oxygen, which is why this process is called aerobic. In fact, most of the ATP created in aerobic respiration is from the final step, chemiosmosis, where oxygen is actually used. Overall, only 2 ATP are created in glycolysis, 2 in the Krebs Cycle, but around 28 total ATP for the chemiosmosis. Now we will look at each step individually.

Glycolysis

In this process, glucose is used and broken down into 2 molecules of **pyruvate**. While it does this, it goes through an energy investment phase where it has to "invest" two ATP molecules for the breakdown to occur. Then, it can "payoff" this energy by creating four new ATP, as well 2 **NADH** molecules from 2 **NADP+** (NADH is similar to NADPH in that it simply carries electrons, known as an electron carrier, while NADP+ is the molecule without an electron attached to it. NADP+ has to be reduced to become NADH). And as we said before, the final product is 2 pyruvates, but it also will form 2 water molecules. Therefore, the final products from glycolysis are 2 pyruvates, 2 water molecules, 2 ATP, and 2 NADH.

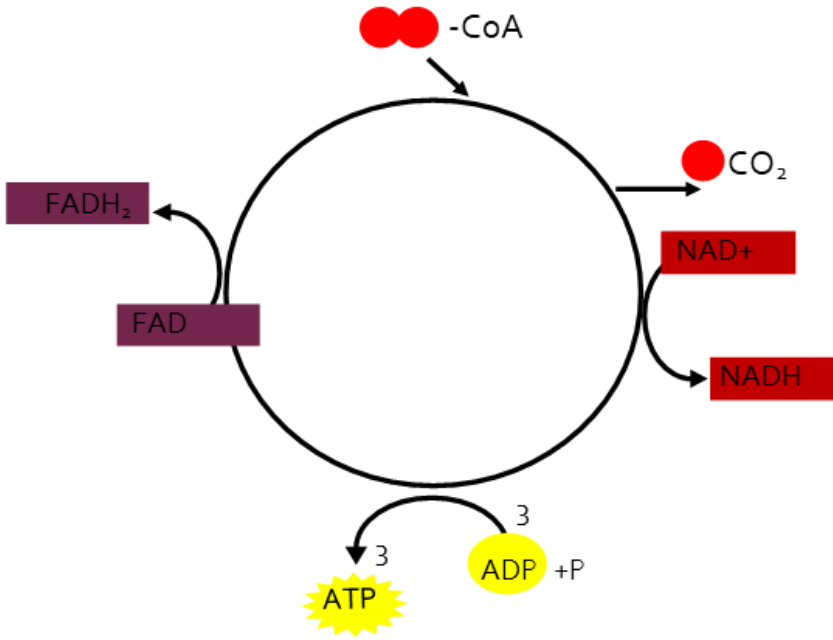


Before it enters the Krebs Cycle, the pyruvate molecule has to undergo some modifications within the matrix. The reactants in this process are, of course, the pyruvate molecule, but another NADP+ is added, and a molecule called **Coenzyme A**. The products are another NADH electron carrier, carbon dioxide, and the coenzyme A attaches to the once pyruvate to create **Acetyl CoA**.



Krebs Cycle

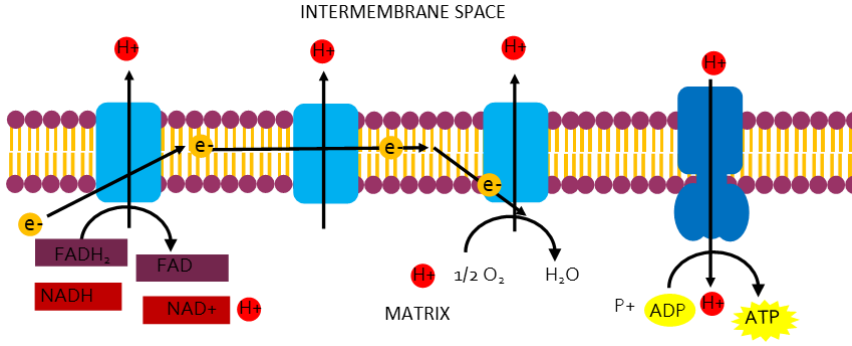
This process is referred to as a cycle because it regenerates a four-carbon molecule. However, the details of the carbon molecules in this cycle are not as crucial as in the light-independent reactions of photosynthesis. The most important steps can be summarized here:



1. Coenzyme A is released before entering the cycle
2. 2 Carbon Dioxide molecules are released from the cycle
3. 3 NAD+ molecules gain an electron to become NADH.
4. One ADP and phosphate group turn into its energy form, ATP.
5. Another electron carrier, **$FADH_2$,** is created from the addition of an electron to **FAD**.

This entire process must occur twice per glucose molecule, so the final products are 4 carbon dioxide molecules, 6 NADH, 2 $FADH_2$, and 2 ATP.

Chemiosmosis



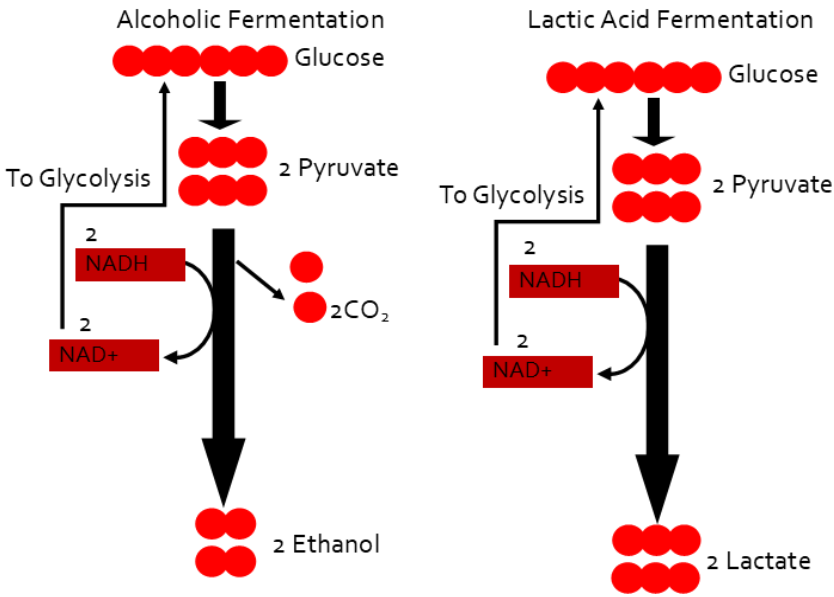
This final step is where the electron carriers finally have their use. NADH and $FADH_2$ molecules will bring their electrons down proteins embedded within the inner membrane known as the electron transport chain, or ETC. As the electrons travel down the proteins, they will pump protons from the inner membrane of the mitochondria to the intermembrane space, creating a large number of protons that want to travel down its concentration gradient. Sound familiar? This is the same thing that happens during the light-dependent reactions of photosynthesis, but now, as the protons escape through the ATP synthase to the less densely populated matrix (thus creating the large amounts of ATP that cellular respiration was intended to create), oxygen takes the Hydrogen protons and creates water to be released

by the mitochondria. Because of this, oxygen is called the final electron acceptor.

Did you know?

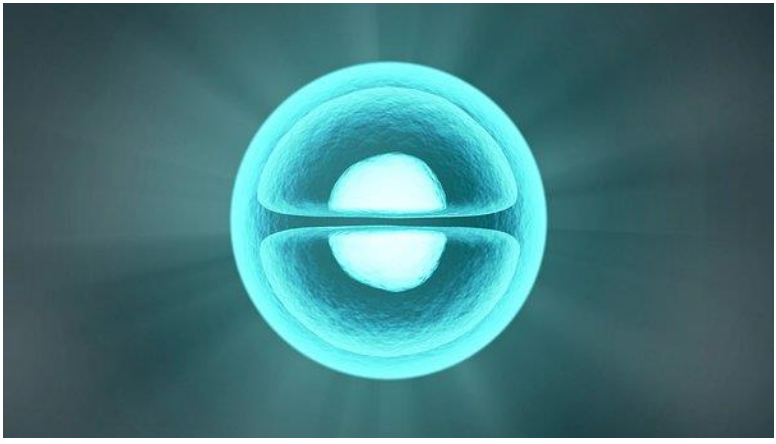
The Krebs Cycle can also be called the Citric Acid Cycle. These two terms are interchangeable. Also, sometimes the term electron transport chain is grouped with the step of chemiosmosis because the entire process essentially accomplishes the singular task of making ATP from electrons pumping protons against its concentration gradient.

Anaerobic Respiration



But what happens when oxygen is not available to produce ATP? The answer is that chemiosmosis is not able to occur because oxygen is not there to accept the protons. Furthermore, the Krebs cycle is not necessary because electron carriers are not needed to move electrons across the ETC. However, when oxygen is absent, the process of **anaerobic respiration** can still function with glycolysis. There are two main types of anaerobic respiration: **Alcoholic fermentation** and **Lactic Acid Fermentation**. The former occurs in yeast, and the latter occurs in muscle cells when your body lacks enough oxygen. As stated, both will undergo glycolysis to produce pyruvate, and each type will then undergo their individual reactions to recycle the electron that is on NADH (remember, NADH is not needed because electron carriers are no longer purposeful. However, if we want glycolysis to repeat to produce the 2 ATP, NAD+ is necessary). In addition, ethanol and carbon dioxide are produced in alcoholic fermentation, while lactate is formed in lactic acid fermentation. Overall, the purpose of anaerobic respiration is to undergo glycolysis to produce small amounts of ATP and repeat glycolysis by replenishing the electron carrier. Because it only creates small amounts of ATP, we can understand why aerobic respiration is much more efficient.

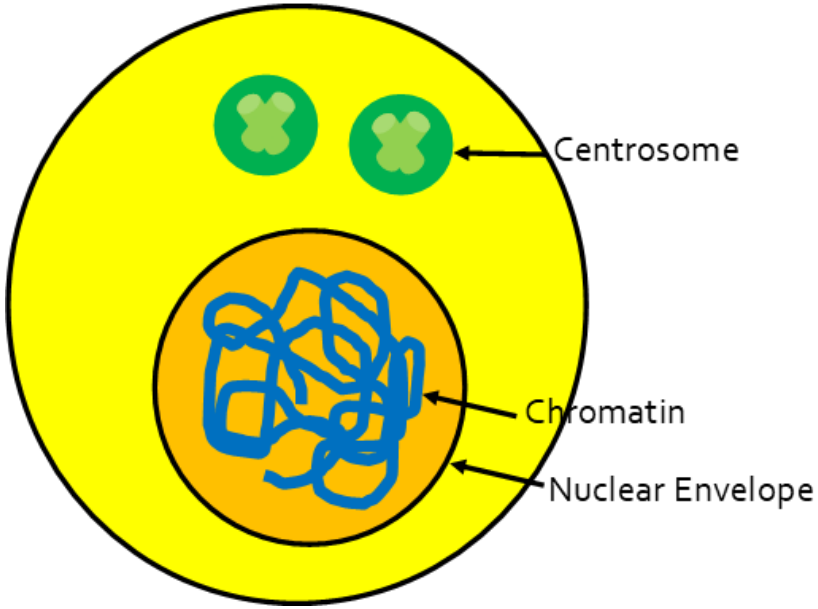
Topic 3.4 Cell Division



For organisms to grow larger, rather than making their cells larger, they actually increase the total number of cells that they have. They accomplish this through a process known as cell division, where one cell divides into two, those two will divide into four total cells, then those four into 8, and so on.

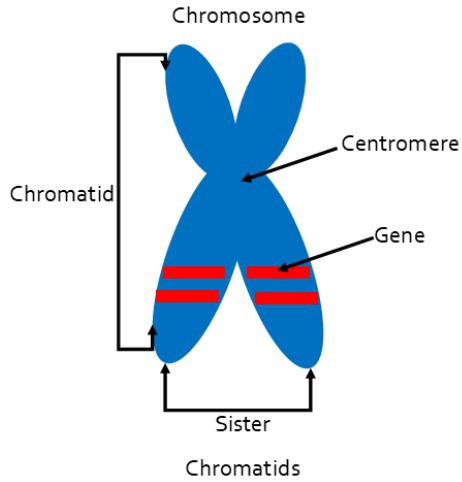
Overview

The process in which a cell divides is known as **mitosis**. The main function of mitosis is to divide the nucleus, which will create two exact copies of a cell from a single cell. Mitosis occurs in all cells in the body with the exception of sex cells such as sperm and egg cells. Cells spend most of their lives not dividing, however. For the majority of a cell's life, they have DNA that is loosely organized inside of the nucleus. This organization of DNA is known as **chromatin**. All the DNA that is found inside a living organism is known as the **genome**.



As the cell continues to live without dividing, it is called **interphase**. Interphase is separated into 3 main steps: G_1, S, and G_2. In the **G_1 phase**, the cell grows larger (think "G" for grow). However, not all cells will continue past this

point. Some cells that no longer want to divide will enter the **G_0 phase** will exit this cell cycle and will undergo their normal processes. The cells that do want to continue the cell cycle will proceed to the **S phase**, where all the DNA that is inside the nucleus will be copied. Now, there are two copies of the organism's genome, which will be important for later when the cell does want to divide. Then, in the **G_2 phase**, the cell will grow some more.

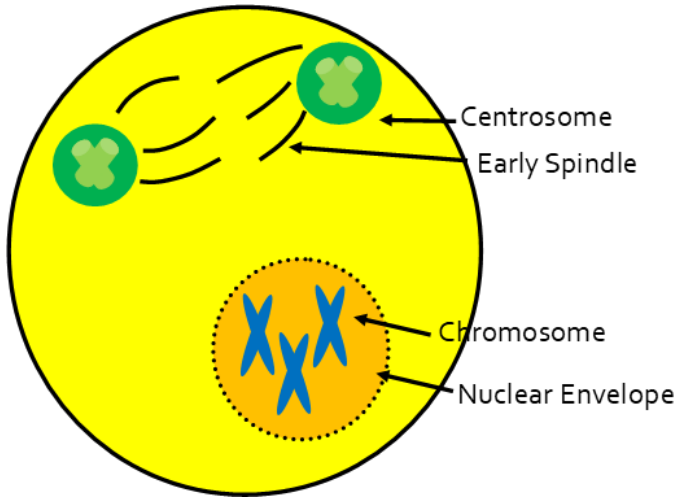


After the cell grows to the point where it is large enough to split into two, it will move on to the mitotic part of the cell cycle, in which cell division will occur. Now is a good time to introduce the idea of a chromosome. A **chromosome** is a group of clustered DNAs and is a single "unit" of the genome. In most human cells, called **somatic cells**, there are 46 total chromosomes, with 23 deriving from our mom and 23 from our dad. In the middle of each chromosome, there is a **centromere**, where 2 segments of DNA are connected. *But wait, why are there two segments of DNA if a chromosome is only supposed to be a single unit of DNA?* This is because after

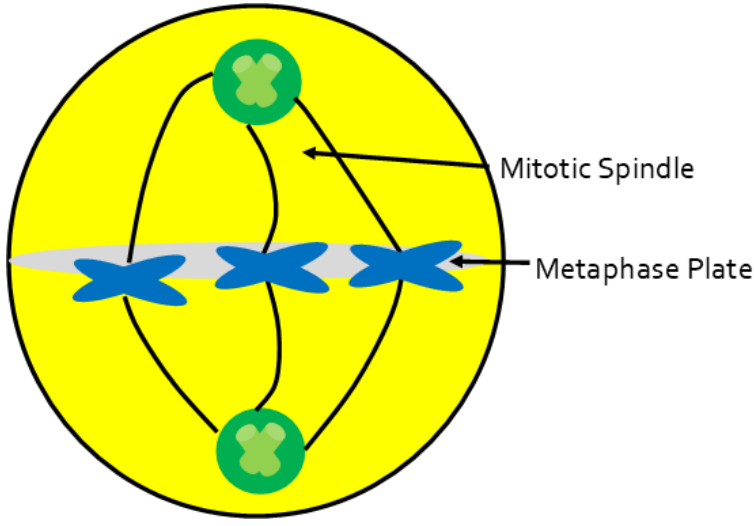
the S phase, we have a duplicated copy of the DNA, and as a result, chromosomes will form with two copies of the same genetic information. Each one of these segments is called **sister chromatids**, and by itself, one segment is called a chromatid. To simplify, whenever you see a chromosome in an "x" shape, it means that there are two copies of the genetic material on one chromosome, while a chromosome is just a single line, there is only one copy of it. Note that in both cases, they represent one single chromosome. On each chromosome, there are many **genes**, which are segments of DNA that code for a specific trait of a human. They are referred to as units of heredity.

With that out of the way, we can introduce the stages of mitosis. The order that they go in is prophase, metaphase, anaphase, telophase, and cytokinesis. Let's discuss each one in further detail.

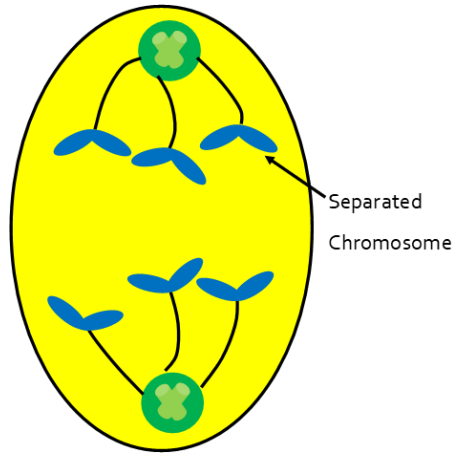
Prophase: In this first step, the loose DNA that is in the nucleus condenses into the chromosomes discusses previously. In a human's case, there are now 46 tightly wounded, double-segmented chromosomes. The nuclear membrane housing the chromosomes will begin the break apart in this phase as well. The **mitotic spindle**, originating from spindle fibers found in the **centrosome**, will begin to form. Two centrosomes will be required to move the chromosomes to two separate sides, and the spindles are going to lengthen.



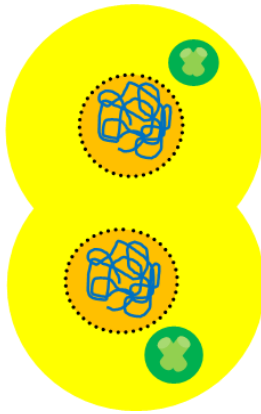
Metaphase: Now that the nuclear membrane is broken, chromosomes can move out into the cytosol and will congregate in a linear formation around the middle, an area known as the **metaphase plate**. The mitotic spindles that were previously created will attach to the centromere, or the middle, of each chromosome (still containing two sister chromatids). The spindles at this point are also on opposite sides of the cell.



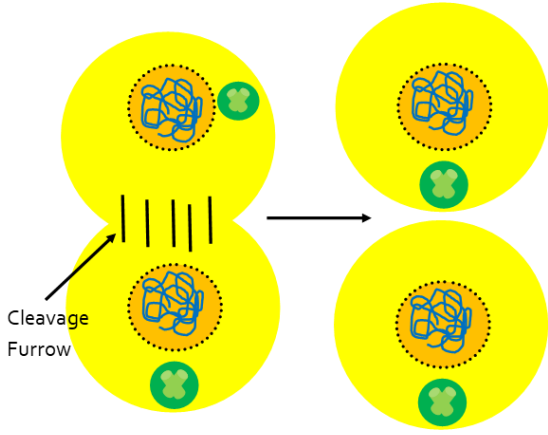
Anaphase: In this phase, the sister chromatids will split into two with the help of the spindles as they shorten. Because the spindle fibers grow shorter and go towards the centromeres, they will pull the sister chromatids apart and cause them to go to opposite sides. We now see the importance of having duplicated genetic information. Each side of the cell now has one copy of the genetic information while maintaining the same number of chromosomes. While this is occurring, the cell will grow longer in preparation to divide.



Telophase: This phase is basically the opposite of prophase: instead of the chromosomes condensing, they will begin to decondense and form the loose structure that it once was, known as chromatin. The nuclear membrane will form once again, this time two separate ones forming on each side of the still unsplit cell. Finally, the spindle fibers will disappear. At this point, mitosis is technically complete since we have divided the nucleus, but there are still not two cells. For this to happen, we go to the next step.



Cytokinesis: In the final part of the cell cycle and after mitosis is complete, the cytoplasm will be split into two separate parts, but the name of where it separates depends on the type of cell. In animal cells, the separation location is called the **cleavage furrow**, whereas in plants it is called the cell plate.



Unit 3 Vocabulary Terms

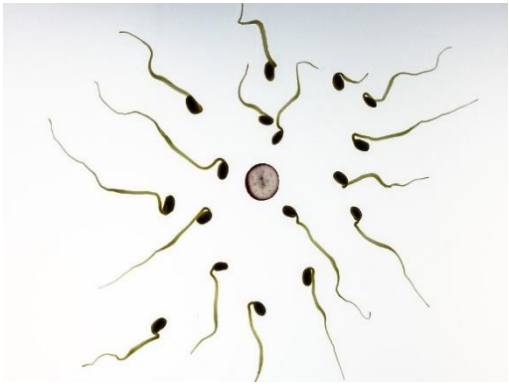
Acetyl CoA
Activation Energy
Active Inhibitor
Active Site
Alcoholic Fermentation
Anabolism
Anaerobic Respiration
Anaphase
ATP
ATP Synthase
Calvin Cycle
Carbon Fixation
Catabolism
Catalyst
Centromere
Centrosome
Chemiosmosis
Chlorophyll
Chloroplast
Chromatin
Chromatin
Cleavage Furrow
Coenzyme A
Cytokinesis
Denature
Electron Transport Chain
Endergonic
Enzyme-Substrate Complex
Exergonic
FAD
$FADH_2$
G_0 Phase
G_1 Phase
G_2 Phase
G_3P
Gene
Genome
Glycolysis
Granum
Inactive Inhibitor
Intermembrane Space
Interphase
Krebs Cycle
Lactic Acid Fermentation
Light-Dependent Reaction
Matrix
Mesophyll
Metabolism
Metaphase
Metaphase Plate
Mitosis
Mitotic Spindle
NADP

NADP+
NADP+
NADPH
Oxidation
Phosphorylation
Photon
Photosystem I
Photosystem II
Primary Acceptor
Product
Prophase
Pyruvate
Reactant
Redox
Reduction
Rubisco
RuBP
S Phase
Sister Chromatids
Somatic Cell
Stomata
Substrate
Telophase
Thylakoid Membrane
Thylakoid Space

UNIT 4: HEREDITY &GENETICS

- 4.1 Meiosis
- 4.2 Mendelian Genetics
- 4.3 DNA Replication
- 4.4 Protein Synthesis and Mutations

Topic 4.1 Meiosis



We have gone over the process of mitosis already, which turned one body cell into two identical cells. However, there are some cells in the body, specifically reproductive cells like gametes, known as sex cells. You will be able to identify each step of this process by the end of this chapter.

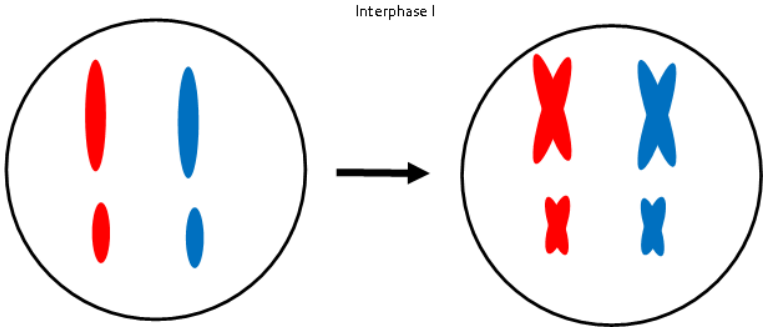
Introduction

Answering the question of what meiosis is, it is the process in which **gametes** (the reproductive cells which include sperms and eggs) are created from the division of a diploid cell. The final product of this division will not be two identical cells like mitosis, but will actually form 4 genetically different cells, which we will see when explaining each step. Keep in mind that most cells of humans contain 46 chromosomes, the diploid number, with 23 coming from your mom and 23 coming from your dad. However, in sperm and egg cells, they will only contain one set of chromosomes, with 23 total. The reason it has to be this way is that for a new person to be created, the egg cell from the mom has to undergo **fertilization** with a sperm cell from the father. When these two haploid cells fuse, they will create a diploid **zygote** with the full 46 chromosomes, which will divide via mitosis to create a new human.

Overall, the process of mitosis is divided into two separate steps, meiosis I and meiosis II. In the prior, homologous chromosomes are split, creating two separate cells with a haploid number of chromosomes. However, in the second process, sister chromatids within each chromosome will split as they did in mitosis. We will look at each phase now.

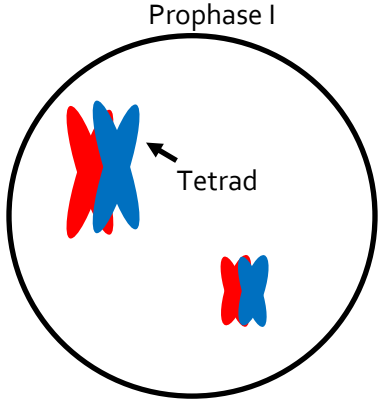
Meiosis I

Interphase I: As a quick note, before Meiosis I begins, chromosomes will be replicated as they did with mitosis. Remember that this doesn't double the number of



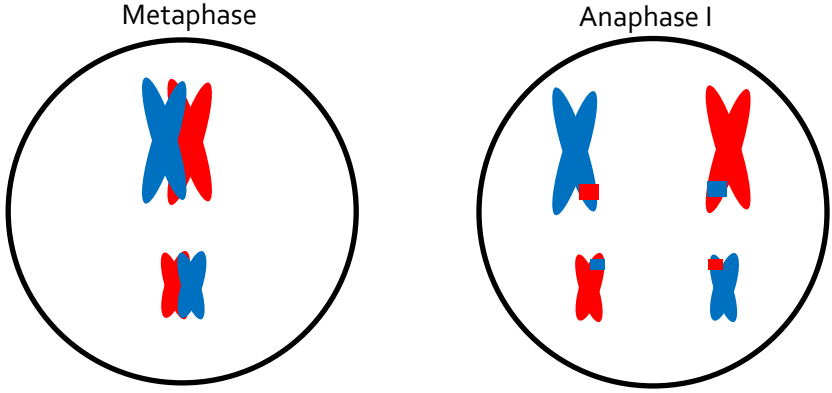
chromosomes. It will only double the number of chromatids, with now 2 sister chromatids on 46 chromosomes. In this diagram, we used 2 pairs of chromosomes for simplicity.

Prophase I: The first step of Meiosis I has very similar steps to prophase in mitosis. The chromatin will condense, the nuclear envelope begins breaking down,

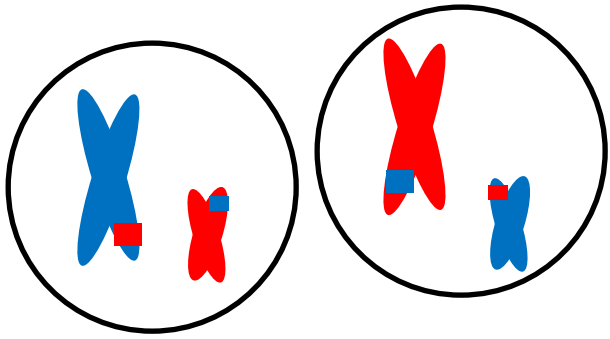


and the spindle begins to form. However, a crucial difference is the process of **synapsis** and **crossing over.** In synapsis, the homologous chromosomes will pair up with each other, forming 23 pairs, with one from each parent. The four sister chromatids combined are now called a **"tetrad"**. While this happens, parts of each pair will overlap with each other and "cross over". The exchanging of segments is what will cause genetic variation when these chromosomes ultimately split apart.

Metaphase I, Anaphase I, and **Telophase I**: These steps are nearly identical to what occurred in mitosis. However, there are a few main differences. Firstly, in Metaphase I, instead of the 46 chromosomes randomly placed in the middle, there will be 23 tetrads that gather on the metaphase plate. As a result, during Anaphase I, the homologous chromosomes will split rather than the individual chromosome, meaning 23 chromosomes will go one side, while another 23 will go to another side. As a result, after Telophase I and eventually cytokinesis, there will be two cells with 23 chromosomes, all of which will have two sister chromatids on them.



Telophase I and Cytokinesis

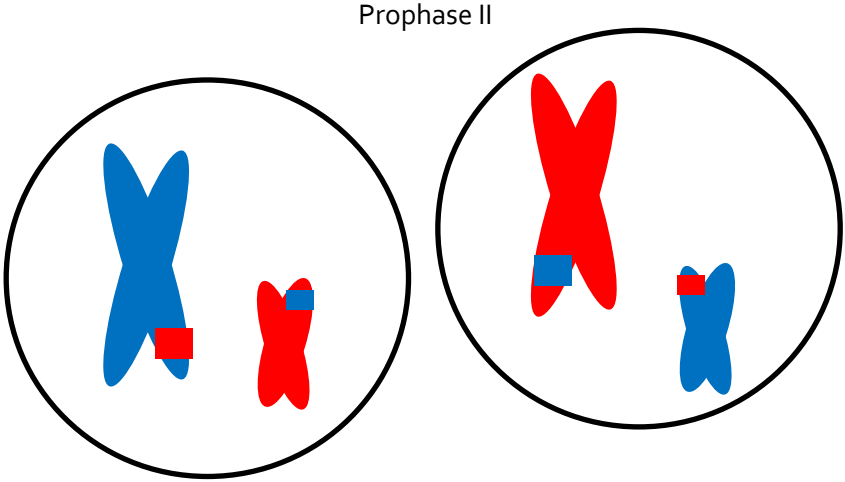


Meiosis II

Now that we have two cells each with 23 chromosomes, they will not undergo another interphase, because there are already two sister chromatids on each chromosome.

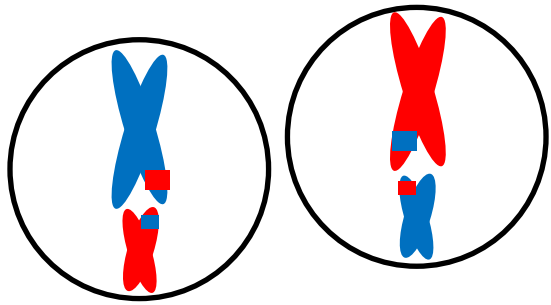
Prophase II: Unlike Prophase I, there will be no exchanging of segments between chromosomes. In this phase, spindle formation is the main event.

Prophase II

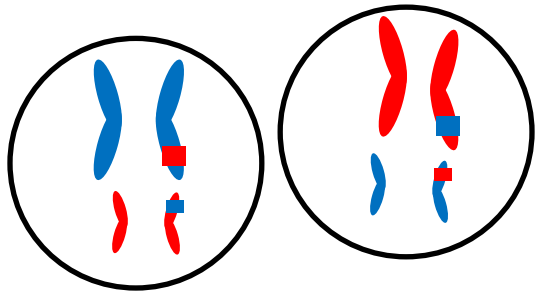


Metaphase II, Anaphase II, Telophase II: Now that chromosomes do not have a pair, they will all align on the metaphase plate and split into two sister chromatids, with 23 going to each side of the cell. After the nuclear envelope reforms in Telophase II and the two cells are once again split, the final product is four final cells each with 23 chromosomes that consist of one sister chromatid.

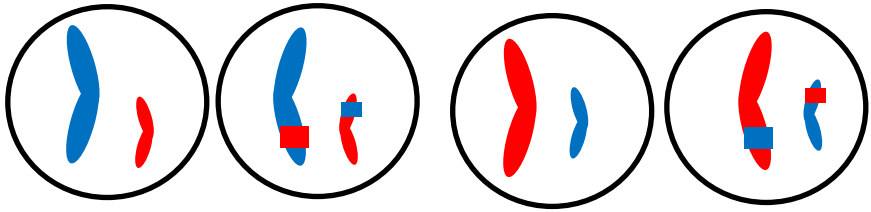
Metaphase II



Anaphase II



Telophase II and Cytokinesis



Topic 4.2 Mendelian Genetics

The word Mendelian comes from the fact that a major contributor to the study of genetics was Gregor Mendel, who is remembered for studying plants such as peas to advance our knowledge in heredity, the passing on of genetic information.

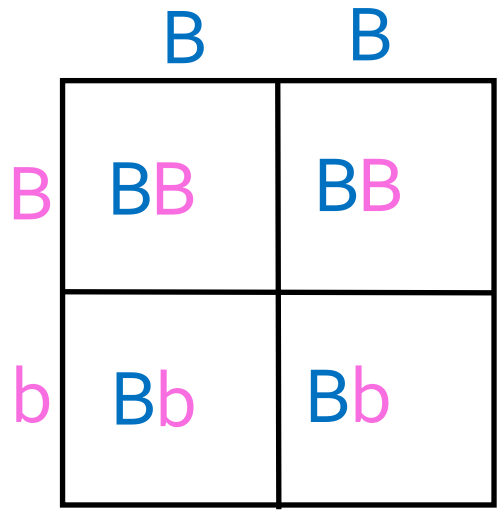
Alleles and Dominance

Recall that a gene is a segment of DNA that codes for a specific trait in a human. Every gene in an organism consists of two different **alleles**, with one from each parent. If the allele is **dominant,** it will be represented with a capital letter, whereas if an allele is **recessive**, it will be represented with a lowercase letter. Alleles will always come in pairs, and the dominance of an allele will determine which one shows. Let's use eye color as an example. Let us also assume that blue eyes are recessive and are designated b, while brown eyes are dominant and are designated B. If you have brown eyes, you can have the alleles BB or Bb for eye color, since the B is dominant and will always show. However, if you have blue eyes, then you can only have bb since both alleles have to be recessive for it to show. All the alleles of an individual make up one's **genotype.** However, the trait that actually appears is known as the **phenotype.** Now we can assign terms for each of the pairs of alleles. Whenever the letters are both capital or both lowercase, it is known as **homozygous** and can be either homozygous dominant or homozygous recessive but if the two letters are different in case, it is called **heterozygous**.

To receive these alleles in the first place, you have to be able to receive if from your parents. Gametes, which are the egg and sperm cells, each have one gene for each specific trait. However, when they combine and form a zygote, each parent will only contribute one of

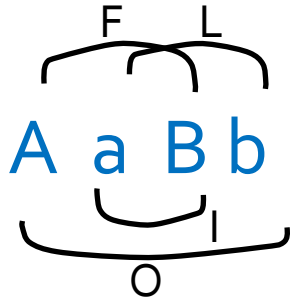
their alleles (out of the two; remember that alleles come in pairs), through a random process known as the **Law of Segregation**. The result is two alleles forming a new gene, with one from each parent. Another idea to keep in mind is that the passing on of one trait does not affect the passing on of another trait; this is called the **Law of Independent Assortment**.

To predict the probability of receiving a certain pair of alleles, we can set up a **monohybrid cross**. On the top of a box, you will write the two alleles that one parent could have contributed, and along the left side, you will write the two alleles the other parent could have given. Then, in each of the four squares, combine the two letters from their respective row and column to receive four total pairs of alleles. The probability of receiving a certain pair of alleles is the fraction that the specific pair appears out of the four total squares. For example, let's say your dad had the homozygous dominant trait for dark hair, while your mom was heterozygous. On the top, you would put BB and, on the side, you would write Bb. Then, taking the letters from each row and column, you get four results of what you could have received. In this specific scenario, you have a 50% chance of receiving the BB



genotype, and a 50% chance of receiving a Bb genotype. However, note that there is a 0% chance of receiving the bb genotype, so the recessive trait will never show.

As expected, things get more complicated when you must combine two traits. However, the basic concept is the same. In this **dihybrid cross**, you will create a 4*4 square. To determine what goes on the top and the side, consider all the possible pairs of the two traits that each parent could have. Let's say that there are two different genes we are accounting for, A/a and B/b. Let's also say that the father has the AaBb genotype. We can use the concept of FOIL (first, outside, inside, and last) to find the four possible pairs that will go across the top.



In this example, F would be AB, O would be Ab, I would be aB, and L would be ab. Let's say that your mother also had AaBb. The four pairs would be the same, and you would write these down the square.

When combining these traits within each box, make sure that the letter a will always go first since that is the first trait, and make sure that capital letters also

precede lowercase ones for each letter. Let us look at the 16 squares.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Here, we can see that each square consists of four letters, with two from each parent, one for the A/a trait and one for the B/b trait. Using these squares can help us to determine probabilities.

Adding on to the memorization, remember that the **P-generation** is the parent generation, meaning the alleles from the parents. The alleles of the children that they produce are known as the **F1 generation**, and the children of the F1 generation are known as the **F2 generation**.

So that's it for Mendelian genetics. However, some untraditional forms of genetics rise that do not adhere to these conventional rules.

Non-Mendelian Genetics

The first of these untraditional types is called **Incomplete Dominance**, so-called because there is no dominant or recessive trait, and as a result, if the child is heterozygous, instead of showing one trait, it will show a blend of both. For example, in flowers, if the R signified a red allele, and the r is the white allele, RR would be a red flower, rr would be a white flower, but if the flower was Rr it would show pink. This is because the R is not actually dominant, and both the red and white allele would contribute towards the child's phenotype.

Somewhat like this is **codominance**, where rather than a blend of traits, both of them would distinctly appear. A common example of this can be shown through chicken color. Usually, in codominance, the two alleles will be designated with two different letters. So, let's say a white allele is W, and a black allele is B. A WW chicken would be white, and a BB chicken would be white. However, a WB (or a BW) chicken would be speckled, having both white and black spots.

Quick Tip:

You can memorize codominance by remembering "co both show".

Next up is when there are **multiple alleles** for one trait rather than the usual two. This is especially prominent in blood type, where there are three different alleles, I^A, I^B, and i. The first two are equally dominant, while the lowercase i is recessive in determining blood type. For example, both an $I^A I^A$ and an $I^A i$ genotype would result in type A blood. Likewise, both an $I^B I^B$ and an $I^B i$ genotype would result in type B blood. However, if the genotype is ii, then it will be neither type A nor type B, so it is considered type O. If the genotype is $I^A I^B$, however, it will have the blood type of AB.

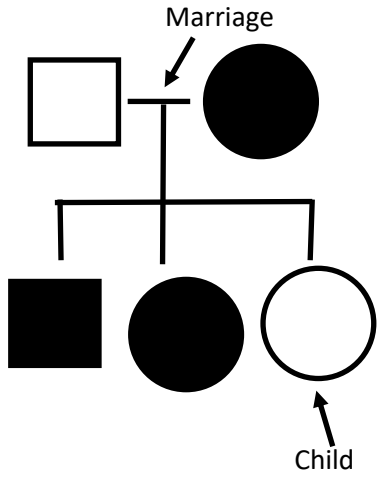
Did you know?

Your blood type, in short, determines the kinds of proteins in your blood. If you have type A blood, you can donate to other people will the A protein, which includes other people with type A, as well as type AB. Similarly, B can donate to other type B and AB blood owners. Type O is known as the universal donor because it does not have the specific proteins. Type AB, on the other hand, can receive blood from all other blood types since it recognizes both the A and B proteins.

Finally, there are sex-linked traits. These traits can only be found on the final, or 23rd pair of chromosomes of a human since that is the one that determines our gender. For this last pair of chromosomes, remember that females have an XX pair of chromosomes, while males have an XY pair. Sex-linked traits can be either dominant or recessive and can either be on the X allele or Y allele. If the trait is X-linked dominant, we can

designate a capital letter for that trait and a lower case letter for the lack of the trait, meaning a female with a phenotype showing the trait could be X^A X^A or X^AX^a, while a male must be X^AY to have the trait since it can only have one X, and whatever is on the one X determines if it contains the x-linked trait. However, if the trait is X-linked recessive, the trait will show on the phenotype only if a female is X^aX^a or a male is X^aY. When crossing a male and a female together, you will realize that two of the boxes have two x's while the other two have an x and a y. The information within these squares can provide probabilities for obtaining the traits for each gender.

We can display all the information about the characteristics of all people within a family tree using a **pedigree**. To keep it simple, a circle is used to represent a female, a square is used to represent a male, a filled-in shape means a person has the trait, while an empty shape means a person does not have a specific trait. We use pedigrees to identify whether a trait is dominant, recessive, or the sex-linked version of the two (if it's not considered sex-linked, it's called autosomal since the trait is on an autosomal chromosome, one of the 22 not used for considering gender). Here is a simple pedigree for an autosomal dominant trait.



Karyotypes

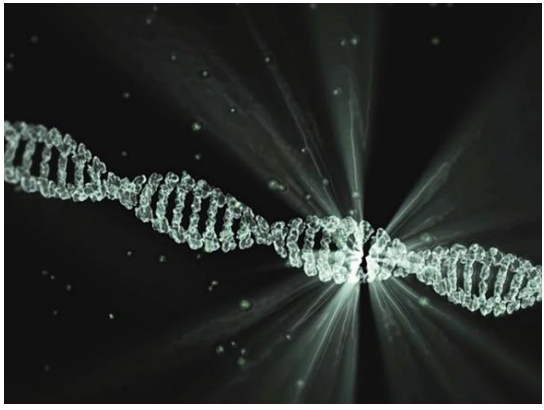
We can analyze all the chromosomes from a human using a **karyotype,** which will show a total of 46 chromosomes with 22 pairs of autosomal chromosomes and one pair of sex chromosomes. Karyotyping can help us identify if there is something unconventional within in, which would mean some sort of genetic disease caused by **nondisjunction** where the homologous chromosomes don't divide properly during meiosis, leading to some offspring having either too little or too many chromosomes. When it has one fewer than expected, it's called **monosomy,** one too many are called **trisomy** (since there are three chromosomes when there should be a pair).

Another way that genes could be altered is through chromosomal mutations. There are four major ones to be familiar with. **Deletion** and **Insertion** are what

you expect them to be: when part of a chromosome is randomly removed or added. **Inversion** is when two parts within the same chromosome switch spots. Finally, **Translocation** occurs when one part of a chromosome detaches and attaches to another chromosome entirely.

Mutations often occur due to random events, or by **mutagens**. However, only the sex chromosomes with mutations will carry on to future generations.

Topic 4.3 DNA Replication



For the genetic information to be passed on to other cells, the DNA has to be replicated, creating two copies of the DNA by splitting the double strand in half and making a copy of each strand. In other words, the two strands will act as a template for making a new strand, and the final product is two identical double-stranded DNA.

The Steps

Since the replication of DNA results in two double helixes each with one "parent" strand, meaning an old strand is paired with a new strand, the process of replication is called **semiconservative**. The entire process involves many proteins as it attempts to successfully create an identical copy of this genetic material.

Firstly, a protein called **helicase** will attach to where the DNA will begin its splitting, and this point is called the **replication fork**. As the helicase opens up the DNA, the hydrogen bonds that are in between the nitrogenous bases of the double helix will break apart.

To ensure that these bonds will not reform and close the DNA up, proteins called **Single-strand Binding Proteins** (SSB) will attach to each strand and keep the two strands separate.

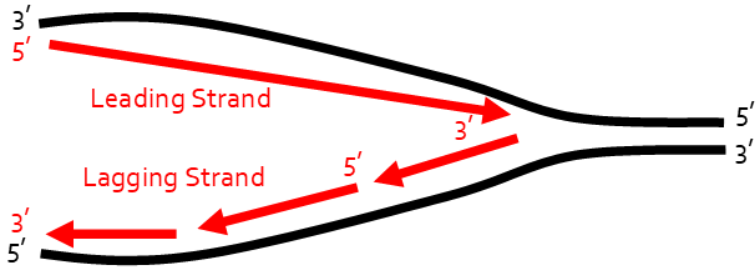
For replication to start, a protein called **Primase** creates a short RNA segment called **RNA primer**, which will generate a short, complementary strand on each side of the DNA. This is where I'll talk more about the antiparallel nature of DNA. In DNA, there are 5 carbons on the sugar. You will remember that the 3rd carbon faces in the opposite direction of the 5th carbon. As each nucleotide forms a single strand, the direction where the 3rd carbon faces are called the **3' end** (three-prime end), while the opposite direction is called the **5' end** (five-prime end). Whenever two strands of DNA are put together in a double helix structure, it will be **antiparallel**, meaning if one strand goes from 3' to 5', the

opposite strand will go from 5′ to 3′. Knowing this information, primase will always create the primer on the 3′ end on each old strand of DNA.

The next protein, **DNA polymerase,** will continue the RNA complementary strand by pairing every A with a T and every G with a C. However, DNA polymerase can only add a strand from the 5′ to 3′ direction. For the old strand that had the helicase unwinding down the 5′ end, the DNA polymerase will be able to add the new strand continuously since the new strand will be antiparallel to the original strand and will start with the 3′ prime end, working its way down. However, on the opposite side, the strand that has helicase running down its 3′ end, an issue arises. Because RNA primers can only be attached to the 3′ end, it will constantly be limited by where the helicase has split open. Therefore, on this strand, there need to be many RNA primases being created, with many strands of DNA being added onto it in the opposite direction to the first strand. After the helicase opens the DNA more, a new RNA primase has to be made at that end to allow for more DNA to be added. The many individual strands that are formed are called **Okazaki fragments**, and since it cannot simply replicate one long strand, it is called the **lagging strand**. The lagging strand will have an old strand moving from 5′ to 3′, and a new strand going from 3′ to 5′ Contrasting this is the one with an old strand moving from 3′ to 5′ and a new strand formed from 5′ to 3′ and is referred to as the **leading strand.**

To avoid gaps in the DNA replication caused by RNA primers, the primers are taken out and replaced by **DNA ligase**.

The result, as you can see in the following picture, is two newly formed double-stranded DNA, each with complementary pairs like the original sequence of DNA. DNA replication is extremely accurate, with an average of one mistake in complementary bases for every 10 billion bases.



Red: Helicase

Purple: Single Strand Binding Proteins

Light Green: RNA Polymerase

Dark Green: DNA Polymerase

Orange: RNA Primers

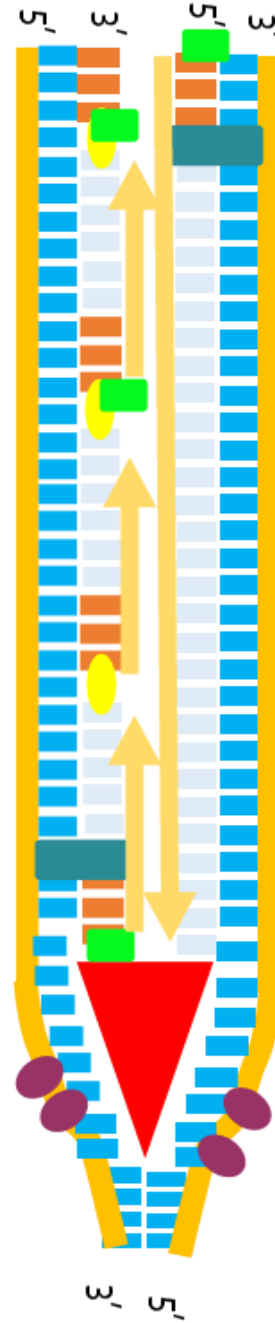
Yellow: DNA Ligase

Bold Yellow and Blue (Top and Bottom Strand): Original DNA

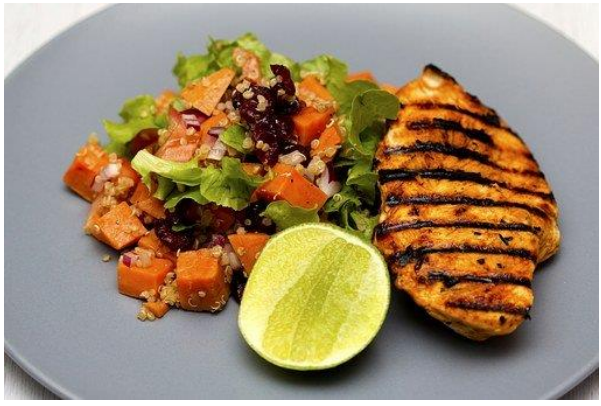
Pale Yellow and Blue (Middle Two Strands): New DNA

Top replicated strand: Leading Strand

Bottom replicated strand: Lagging Strand



Topic 4.4 Protein Synthesis and Mutations



Proteins are a crucial macromolecule for the cells as is serve as enzymes as well as regulate most human processes. To create it is a long and complicated process, and I will attempt to simplify it here.

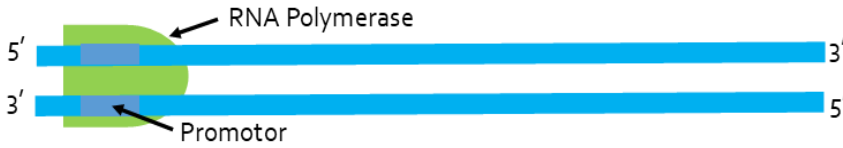
Introduction

As an overview of protein synthesis, proteins must be created by the genetic code offered by DNA. Recall in the organelles section that ribosomes are the ones that create proteins. Since DNA cannot simply go out of the nucleus of a eukaryotic cell such as in humans, DNA has to be converted into something else. This "something else" is RNA, or more specifically, **mRNA**, standing for messenger RNA. The mRNA can combine with a ribosome within the cytoplasm to create the proteins. This entire process, in which DNA goes to mRNA, which then becomes a protein, is called the Central Dogma of Biology. The transition from DNA to RNA is called **Transcription**, while the transition from RNA to protein is called **Translation**. These two major steps will be discussed next.

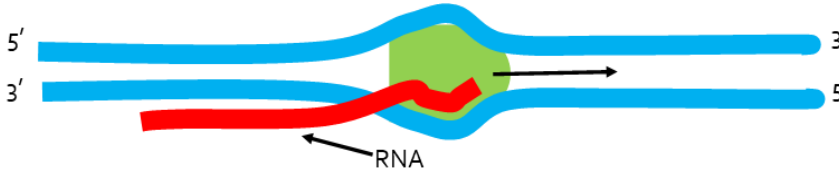
Transcription

Using the DNA code, a single strand of mRNA is created. This process is split into three steps:

1. **Initiation**: Unlike DNA replication a primase is not required to begin adding complementary bases. Similar to DNA replication, it will require a polymerase, but this one will be called **RNA polymerase** since it's creating an RNA code. The polymerase will attach to a beginning spot called the **promotor**.



2. **Elongation**: Instead of adding complementary strands on both original DNA strands, it will only add nucleotides from the 3′ to 5′ direction (since ribose is also a 5-carbon sugar it will also have opposite-facing the 3rd and 5th carbons. Therefore, it will use the 5′ to 3′ DNA strand as a template strand, also called the sense side, with the untranscribed strand called the antisense strand, or sometimes called the coding strand since similar to the new RNA code, it has a complementary



sequence to the template strand. However, since there are no thymine nucleotides in DNA, every time the template DNA has adenine, it will match will a U from RNA.

3. **Termination:** After the mRNA reaches a certain point called the **termination point**, it will detach and now can travel out of the nucleus. However, this mRNA is not completely ready to be translated and is referred to as pre-mRNA. To fully become the RNA transcript in eukaryotic cells, some changes need to be made.

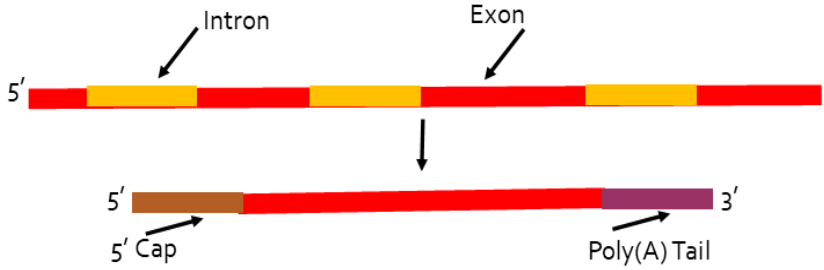
Setting up for Translation

In eukaryotic cells, the RNA code needs to be modified to successfully be translated into a protein. At the 5′ end, a **5′ cap** is added, which will indicate the start of the translation. Then, on the 3′ side, a **Poly(A) tail** is added, which is named so because it consists of a lot of adenine nucleotides.

Then, in the middle of the mRNA, there consist two different regions: **introns** and **exons**. Introns are not used in the coding of the protein, so they are taken out by a molecule that is called a spliceosome. On the other hand, exons stay within the strand.

Quick Tip:

"Ex"ons are "Ex"pressed, so they remain in the mRNA code.



Translation

Translation involves the usage of three different types of RNA. The first one, mRNA, is the one that we have already talked about. It consists of the genetic information that was created from the DNA. The second type of RNA is Ribosomal RNA, or **rRNA**, which is the actual ribosome, the site of protein production. It has a small and large subunit, and three different sites, the A, P, and E sites. These sites where the third type of RNA will attach, transfer RNA, or **tRNA**.

To get from RNA to a protein, we must discuss what a **codon** is. Recall that polypeptides, or proteins, are made up of amino acids. Turns out, there are only 20 different amino acids, and each one is coded by 3 nucleotide bases. Therefore, a group of three letters is known as a codon since it encodes for a single amino acid.

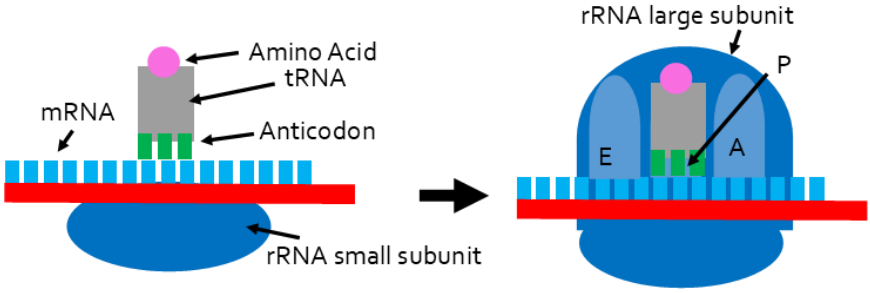
Did you know?

There is a total of 64 total codons, since each codon is 3 letters, and each spot has 4 possible options: A, U, C, and G. Therefore 4x4x4 = 64. However, there are only 20 different amino acids. This means that some codons will code for the same amino acid.

An **anticodon**, then, is something specifically on tRNA, and it consists of three complementary letters to the amino acid it holds. In other words, tRNA is made up of an amino acid, as well as the anticodon that it corresponds to. The steps in which all these parts are

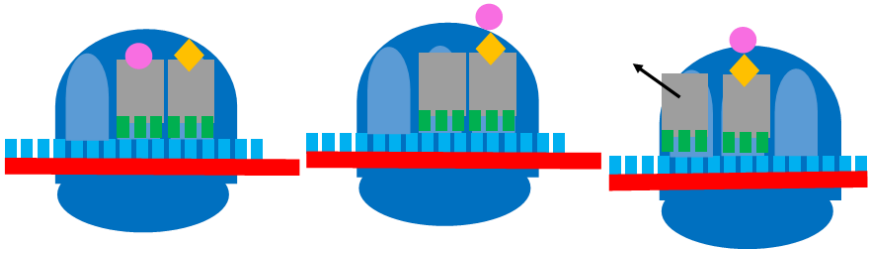
involved is the same as transcription, but the details of each are different.

1. Initiation: The mRNA attaches to the small unit of the rRNA at the 5′ end. Then, a tRNA with the anticodon will attach to the corresponding mRNA code. For example, the first codon on the mRNA is usually AUG, which corresponds with the amino acid called methionine. Therefore, a tRNA molecule with the anticodon UAC will attach to those three letters, and on the opposite side of the tRNA is the first amino acid. Then, the large subunit will attach the entire thing, at the P site, and the **translation initiation complex** is created.

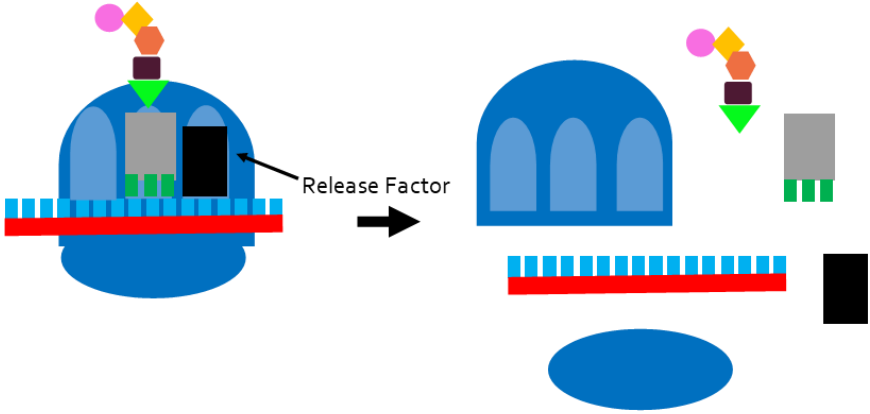


2. Elongation: The three letters from the mRNA in the A site will cause another tRNA molecule to pair up with it. Then, the amino acid from the P site will move over to the one on the A site, creating the polypeptide chain. Then, both tRNA molecules will move left in a process called translocation, and the one now at the E site will exit. Now, the A site is once again open, where a new tRNA can attach, take the existing polypeptide chain and attach it to

its own amino acid, and move the other tRNA down to exit. This process will continue, making the protein longer.



3. Termination. Once the mRNA has a codon specifying that translation should end, a release factor goes to the A site, the rRNA breaks apart, and the protein is released to carry out its function.



Mutations

Mutations that occur during protein synthesis are commonly caused by mutagens. Several types of mutations can happen to the mRNA that can cause incorrect proteins to be created or even cause the absence of protein production.

The first type of mutation is called a **point mutation**. This is a broad term referring to whenever only one base pair of the mRNA chain is changed. There are three main types: **substitution** exchanges one base to another, while **deletion** and **insertion** with do what they say, deleting or adding one nucleotide to the mRNA. Both of them can cause something called **frameshift mutation.** Since mRNA creates amino acids by reading the letters in triplets, if one single letter was deleted, all the letters would shift over one, causing all amino acids created after that to be incorrectly coded.

A **silent mutation** occurs when the nucleotide replacement does not change the amino acid it creates. This is possible since some codons can code for the same amino acid.

A **missense mutation** occurs when the nucleotide that is changed does change the amino acid that it creates.

Nonsense mutations occur when the new amino acid created causes the new codon to be a stop codon, which will prematurely end the process of translation.

Unit 4 Vocabulary Terms

3′ End
5′ cap
5′ End
Allele
Anaphase I
Anaphase II
Anticodon
Antiparallel
Codominance
Codon
Crossing Over
Deletion
Deletion
Dihybrid Cross
DNA Polymerase
Dominant
Elongation
Exons
F_1 Generation
F_2 Generation
Fertilization
Frameshift Mutation
Gametes
Genotype
Helicase
Heterozygous
Homozygous
Incomplete Dominance
Initiation
Insertion
Insertion
Interphase I
Introns
Inversion
Karyotype
Lagging Strand
Law of Independent Assortment
Law of Segregation
Leading Strand
Ligase
Meiosis
Meiosis I
Meiosis II
Metaphase I
Metaphase II
Missense Mutation
Monohybrid Cross
Monosomy
mRNA
Multiple Alleles
Nondisjunction
Nonsense Mutation
Okazaki Fragments
P Generation
Pedigree
Phenotype
Point Mutation

Poly(A) Tail
Primase
Promotor
Prophase I
Prophase II
Recessive
Replication Fork
RNA Polymerase
RNA Primer
rRNA
Semiconservative
Silent Mutation
Single-Strand Binding Protein
Spliceosome
Substitution
Synapsis
Telophase I
Telophase II
Termination
Termination point
Tetrad
Transcription
Translation
Translation Initiation Complex
Translocation
Trisomy
tRNA
Zygote

UNIT 5:
BODY SYSTEMS

- 5.1 Skeletal, Muscular, Nervous
- 5.2 Circulatory and Respiratory
- 5.3 Digestive and Excretory
- 5.4 Integumentary and Immune
- 5.5 Reproductive and Endocrine

Topic 5.1 Skeletal, Muscular, Nervous

As we enlarge our scope out of the cell and expand to create tissues and organs, we get our organ systems, which is a group of organs working towards a single goal. These three body systems are crucial for body support, movement, as well as allowing humans to think.

Overview

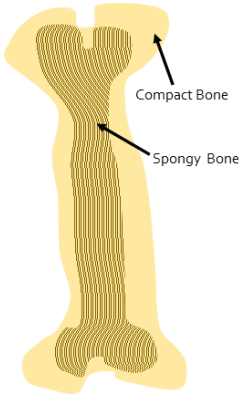
So what are organs even made of? Organs consist of many tissues that work together. There are four main types of tissues. **Epithelial** tissue is found on the skin surface, which will be seen in the integumentary system. **Nervous** tissue is found within the nervous system. **Connective** tissue is any tissue that connects and supports other types of tissue. Finally, **muscle** tissue consists of three different types: **smooth** facilitates internal body functions, **skeletal** helps to move the body, and **cardiac** is found in the heart.

The job of these organ systems is the maintain **homeostasis**, which is keeping the human body normal even when subjected to outside conditions. Examples of homeostasis involve maintaining a constant internal temperature, keeping the fluids in your body regulated, as well as metabolizing at normal rates.

Skeletal System

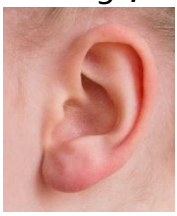
The jobs of the skeletal system are to, as expected, create a framework of the body to support itself. However, it also has numerous other functions, such as working with the muscular system to move, protecting other organs, as well as producing blood cells.

As you may have heard before, the human body consists of 206 total bones, but what are bones actually made of? All bones in the body have a section called the **spongy bone** on the inside, with the harder **compact**



bone surrounding it, which is the part that we most commonly see. Bones are made up of calcium, which is the component that makes it hard. As humans grow, the bones will grow longer as well as thicker.

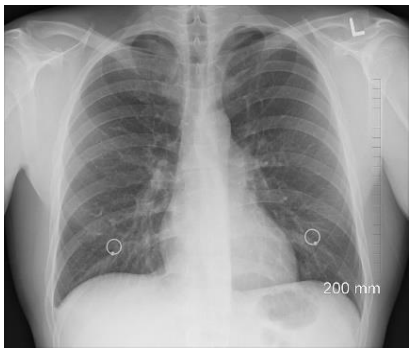
The human body is made up of two "parts" of the skeleton. The **axial** part consists of the vertical column starting from our skull down to our waist area. This includes the spine, ribs, as well as our sternum. The **appendicular** part of the skeletal system, on the other hand, is everything else, notably the limbs like our arms and legs, as well as our shoulders.



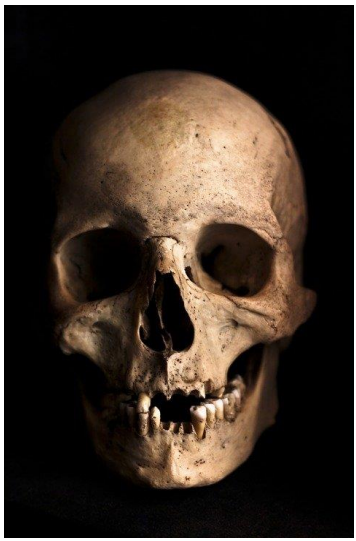
In some parts of the body, we do not actually have bones, but we do have something called **cartilage**, which is elastic and can be found in places like your ear.

Joints are where two bones are connected. Depending on the type of joint, they can have different roles and movement capabilities. The **semi-mobile joints**, such as those found in the ribs, spine, and vertebrae, have limited movement. The skull, which cannot move at all, is called an **immovable joint**. **Cartilaginous joints** are joints that are connected by cartilage and are only somewhat flexible. The more moveable joints are called **synovial joints**, and there are many different types. Two main examples are the **ball-and-socket** joint, which can move in a circle like the hip joint, and the **hinged joint** which can only move in one axis, like the elbow.

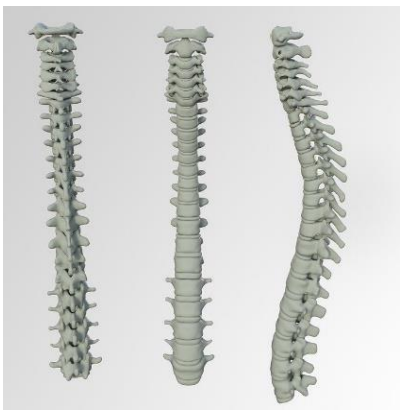
Bones are connected at joints with tissues called **ligaments,** while when a bone attaches to a muscle, it does so with a **tendon.**



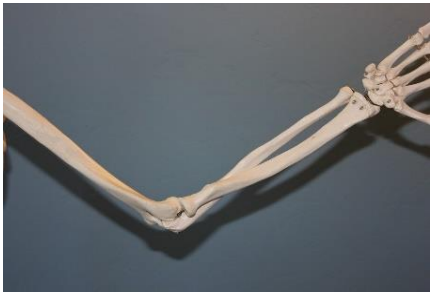
Semi-Mobile



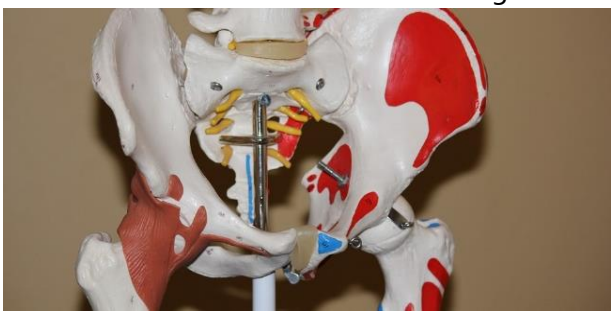
Immovable



Cartilaginous



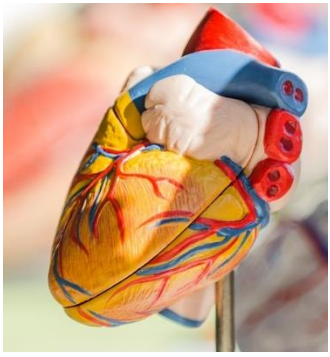
Hinged



Ball-and-Socket

Muscular System

The muscular system's function is to help the body move, as well as to take care of internal functions. The muscular system is separated into two parts: the involuntary muscles and the voluntary muscles.

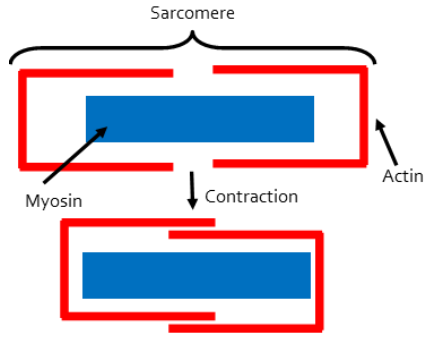


Involuntary muscles are involved in carrying out tasks that you are not conscious of doing. This involves the smooth muscles, which can contract in vessels and digestive pathways to move substances around. It also includes the cardiac muscles, which are found in the heart.

Voluntary muscles are the traditional muscles that you think of when you hear "muscles", and you use them for any movement that you are conscious of, from walking to hitting a baseball. This includes the skeletal muscles, which attach to the skeletal system and will contract for movement.

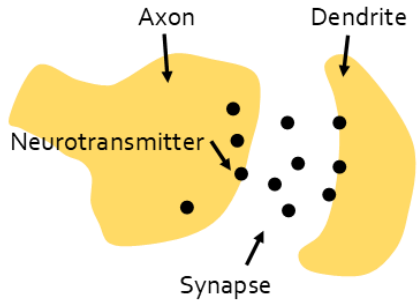
For contraction to occur, the skeletal muscles must become shorter. The things that become shorter are known as **sarcomeres**, one unit of a skeletal muscle. Sarcomeres are formed from filaments called **actin** and **myosin**, with the former being thinner and the latter being thicker. These filaments slide past each other and

will compress the entire sarcomere, which will lead to muscles contracting.

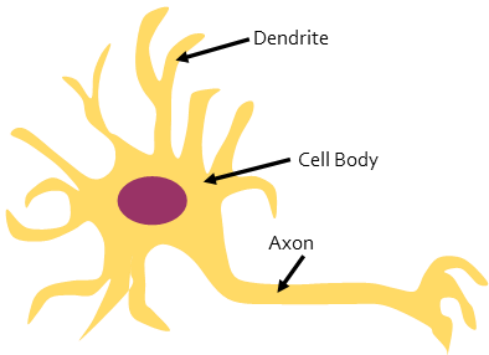


Nervous System

The function of the nervous system is to allow us to make cognitive decisions, as well as allow identify and perceive emotions. The nervous system is composed of cells called **neurons**. There are three main parts of a neuron to be familiar with. The **dendrite** is one of many short, branching segments that will receive a signal from another neuron. The information that is received is usually an electrical signal, and these are called **nerve impulses**. The second part of the neuron is the cell body, which the main, central location of the cell and receives information from the dendrites. It is



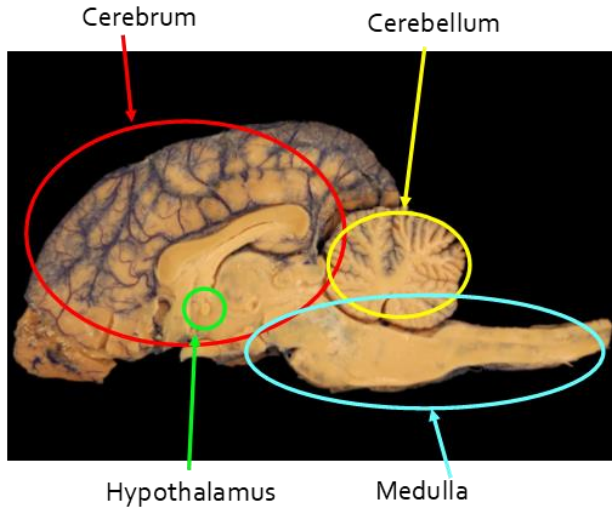
also where organelles like the nucleus are found. The electric signal will make its way to the **axon,** which will then send the impulse out and to another neuron's dendrite. The space between two neurons is called a **synapse**. When the electric signal is sent, neurons are not actually touching, and instead, the signal will "jump" to the next neuron with chemicals called **neurotransmitters.**



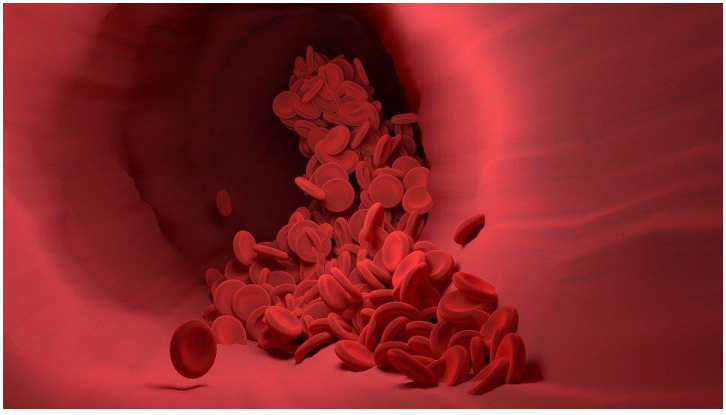
The nervous system is made up of two main parts. The **Central Nervous System** (CNS) is made up of the brain, as well as the spinal cord. It receives information from the second part, the **Peripheral Nervous System,** and responds accordingly to the information it gathers from it. The Peripheral Nervous System, or PNS, is basically everything except the brain and spinal cord and is separated into **sensory neurons**, which send information about our five senses, and **motor neurons,** which tell the CNS information about muscular movement.

Returning to the brain, it is made up of four main parts: the **cerebrum** is in charge of voluntary actions, the **cerebellum** takes care of balance and muscle control, the **medulla,** which takes care of involuntary actions such as

breathing and heart beating, and the **hypothalamus** controls the pituitary gland of the endocrine system (more on it later).



Topic 5.2 Circulatory and Respiratory



These two body systems are extremely interconnected because the job of the circulatory system is to carry blood containing oxygen around the body. To gain this oxygen, we must utilize the respiratory system, thus creating a dependent relationship.

Circulatory System

The circulatory system, also called the cardiovascular system, has the job of carrying blood around the body. Blood, while being a liquid, is actually a type of tissue that consists of many types of cells. For example, red blood cells, or **erythrocytes**, are the cells that carry oxygen. It can do this with the help of a protein called **hemoglobin**. In addition to red blood cells, the blood also is made up of white blood cells, or **leukocytes**, which are involved in taking care of diseases. Also, **platelets** are found in the blood and will travel to locations where blood clotting is required. However, for these three types of blood cells to travel around the body, they must be situated within a liquid substance, which is called **plasma**.

Before we talk about how blood travels through the heart, we have to talk about the blood vessels, the tubes that plasma along with the cells travels in. There are two main classes of blood vessels: **Arteries** carry blood away from the heart, while **veins**, carry blood towards the heart. Both types of vessels also consist of extremely small vessels called **capillaries**. These are involved in the exchange of oxygen and carbon dioxide in blood cells.

Quick Tip:

"A"rteries carry blood "A"way from the heart, while Veins do the opposite.

As stated earlier, the function of this system is to bring blood with oxygen, or oxygenated blood around the body, while also replenishing blood without oxygen or deoxygenated blood. In general, the atria bring

oxygenated blood away to the rest of the body, while the veins bring deoxygenated blood to the heart. However, we will see later that this is not always the case.

Crucial to the circulatory system is the heart, an organ made up of cardiac muscle and four main chambers. The top two chambers are called **atria**, and the bottom two chambers are called **ventricles.** When looking at a diagram, the two chambers on the left are called the right atria and right ventricles, while the two chambers on the right are called the left atria and ventricles. The reason that it is the opposite is that the chambers were named based on how they are oriented on yourself, therefore being reversed when placed in front of you.

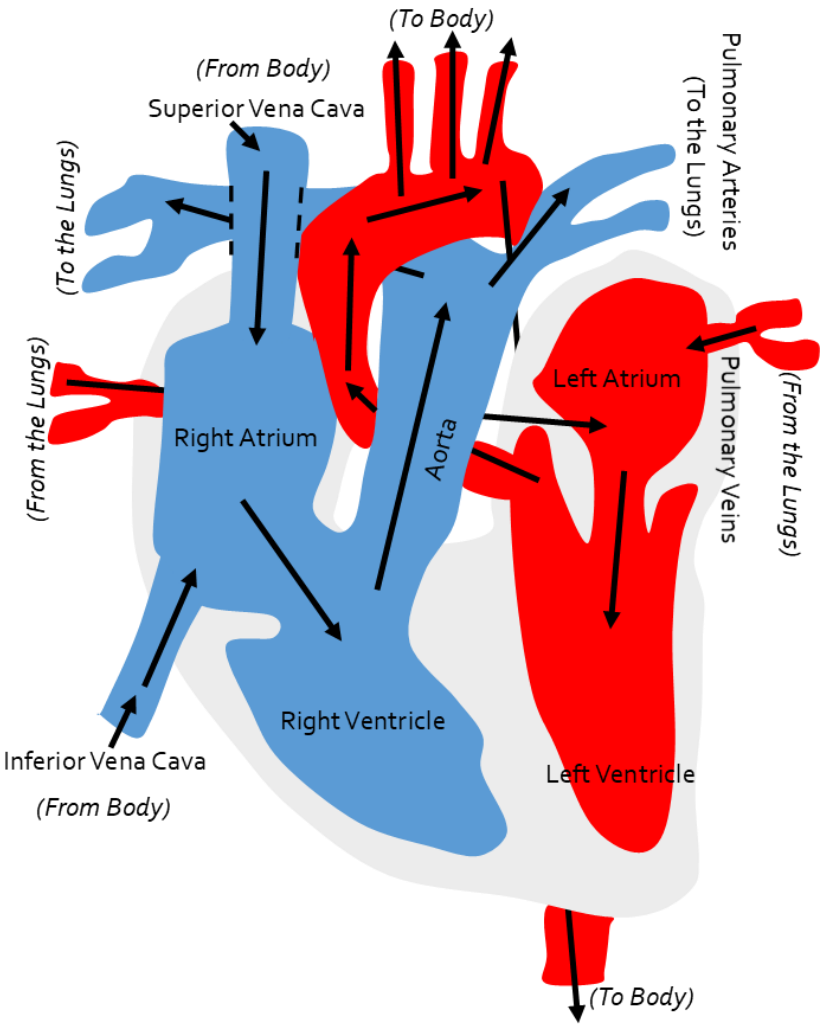
Now we can discuss how the blood travels throughout the body. First, deoxygenated blood will enter the heart through the **vena cava**, which is the largest vein in the entire system. The vena cava is attached to the right atrium of the heart and will travel down to the right ventricle, passing through a valve called the **tricuspid valve**. The function of a valve is just to ensure that blood does not travel backward. After the blood goes through the right ventricle, it will pass through another valve called the **pulmonary semilunar valve**, exit the heart, and to the **pulmonary arteries**. These arteries still contain the deoxygenated blood, making it an exception to the general rule that blood leaving the heart is

Did you know?

There are two main vena cava; the superior and the inferior. They differ in the location where they enter the heart, with the superior on the top and the inferior on the bottom.

oxygenated. This deoxygenated blood, rather than leaving for the rest of the body, will travel towards the lungs, which is part of the respiratory system. As it goes towards the lungs, the arteries become smaller and smaller until, at the lungs, there are capillaries that will help the red blood cells receive the oxygen that the lung provides. Now the blood is oxygenated and will return to the heart through the **pulmonary veins**. This is an exception to the general rule that vessels traveling to the heart are deoxygenated. The veins will grow in size until it reaches the left atrium of the heart. Then, it will move through another valve called the **bicuspid valve**, and down to the left ventricle. After traveling through another valve called the **aortic semilunar valve**, it reaches the **aorta**, which is the largest artery in the circulatory system. This artery will expand to a system of smaller arteries, and eventually capillaries throughout the entire body. Now the body can receive the oxygen that was in the red blood cells, and once it is used up, it becomes deoxygenated and returns to the vena cava, allowing the cycle to restart.

This cycle, as you have observed, was broken down into two parts: one to gain oxygen from the lungs, and one to send the oxygen throughout the entire body. The first part can be thought of as the **pulmonary circuit** while the second part can be thought of as the **systemic circuit.**

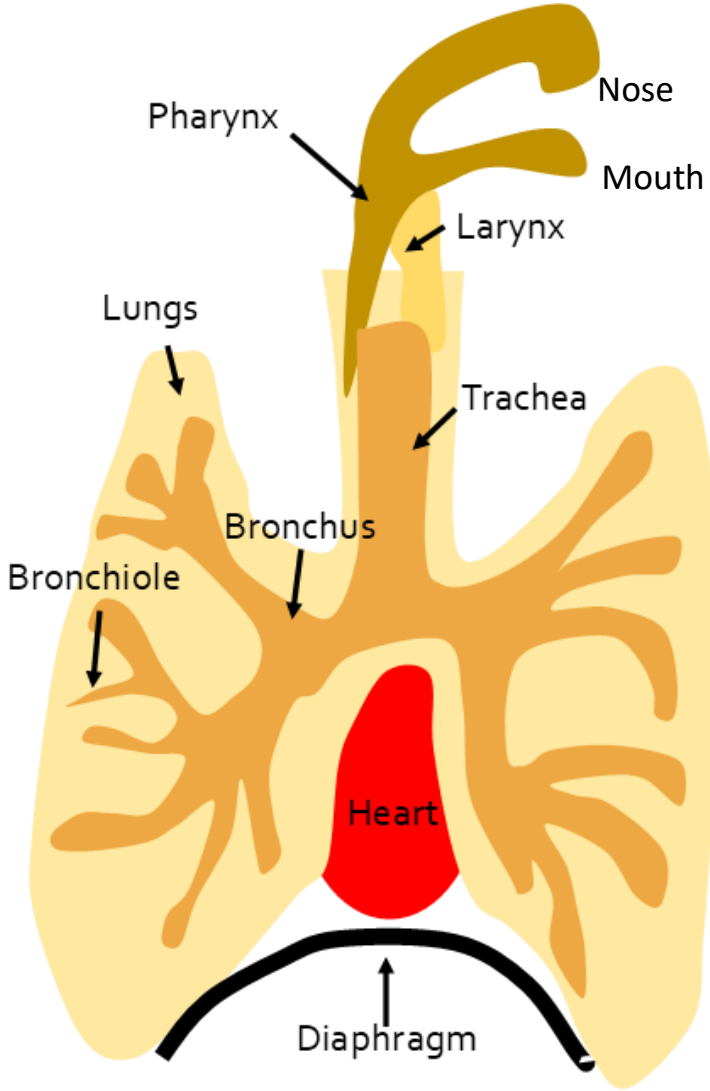


Quick Tip:

Whenever you see blue on the diagram, it does not mean that you have blue blood. It instead signifies that the blood is deoxygenated at that point while red means that the blood is oxygen-rich.

Respiratory System

This system allows the body to take in oxygen through the **lungs,** as well as get rid of carbon dioxide. This process of gas exchange between us and the environment is called **respiration**.



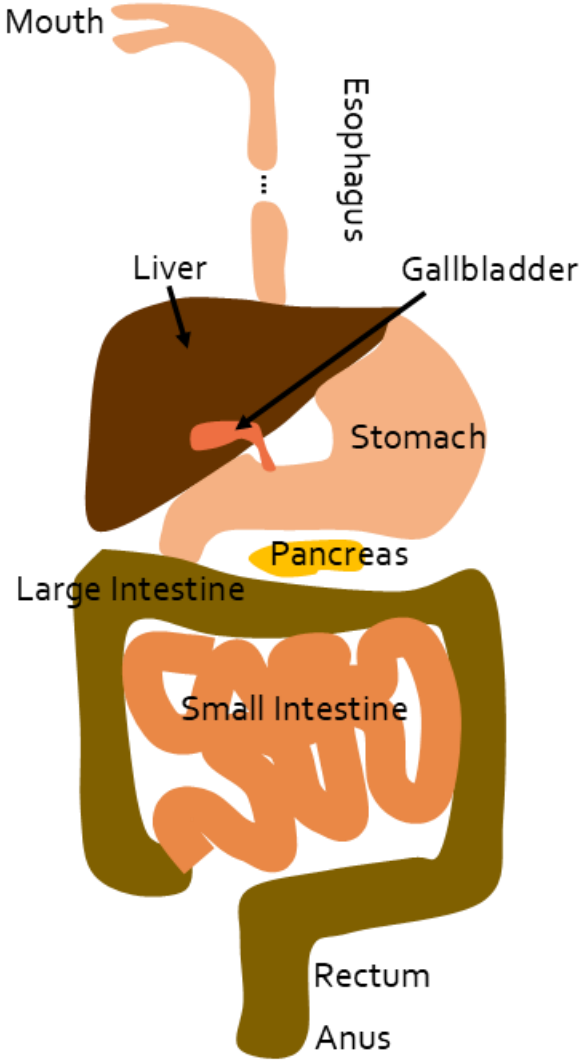
First, air from the environment will enter through our nose (and mouth) and will travel down many pipes, including our throat (also called the **pharynx**), our voice box (also called our **larynx**), as well as the windpipe (also called the **trachea**). Then, inside the lungs, air will travel through large tubes called **bronchi** (singular bronchus), which will then branch out into smaller tubes called **bronchioles**. The air then goes inside small sacs called **alveoli**, which is where oxygen gas is taken in and carbon dioxide gas is taken out. Then, the oxygen goes into the blood cells through the capillaries in the cycle discussed in the circulatory system.

We can respire due to an organ called the **diaphragm**, which rests just below our lungs. When we breathe in, the diaphragm will move down and contract, allowing our lungs to expand and take in the air. Then, as we exhale, the diaphragm will relax, move up, and force the air out through our mouth or nose.

Topic 5.3 Digestive and Excretory

The digestive system is involved with the absorption of nutrients from food and releasing waste, while the excretory system deals mostly with the filtering of the liquid that we consume. Here is more information about both.

Digestive System



The role of this system is to take in the food and nutrients that we eat and either absorb them into our body or excrete it as waste. To do this, it follows the **Gastrointestinal Tract** or the GI. The GI is also referred to as the **alimentary canal,** and it includes all the organs

through which food will actually travel, such as the mouth, esophagus, stomach, and intestines. On the other hand, **accessory organs** are organs that do not receive food but still aid in the breaking down of food. Some of these organs include the pancreas, liver, and gallbladder.

There are two main types of digestion within the system. **Mechanical digestion** breaks down food through movement, while **chemical digestion** does so by using enzymes.

Both types are present at the very beginning of the process of digestion, where food enters through the mouth. Our teeth will mechanically break down that food into smaller pieces, while an enzyme called **amylase**, which is found in our saliva helps to break down macromolecules, specifically large carbohydrates. Then, the food will travel down the **esophagus**, where smooth muscles will contract and push the food downwards in a process called **peristalsis**. Next, the food will move into the **stomach**, where most of the chemical digestion occurs. The food now becomes a liquid-like mush called **chyme**, and enzymes such as **pepsin** aid in the breaking down of more macromolecules, which in pepsin's case, is proteins. After the stomach, the acidic chyme moves into the **small intestine**, where nutrients are absorbed. It can do this since on the inside of the tubes, there are small fingerlike projections called **villi**, which themselves have

Did you know?

Peristalsis is the reason why food will travel downwards even when you are lying down!

smaller projections called **microvilli,** which allows the surface area to increase. When the surface area increases, more nutrients can be absorbed by the body. Also, while the food is in the small intestine, the accessory organs play a role in secreting enzymatic juices. The **liver,** for example, secretes a juice called **bile** which is then stored in the **gallbladder** until it needs to be released. The function of bile is to break down lipids into fatty acids. Another accessory organ, the **pancreas**, also secretes its own pancreatic juices into the chyme to break it down further. After the small intestine, the food goes toward the **large intestine**, which does not participate in either mechanical or chemical digestion. Instead, it absorbs the water from the chyme and leaves the solid waste. Then, that waste will travel to the **rectum**, and exit through the **anus**.

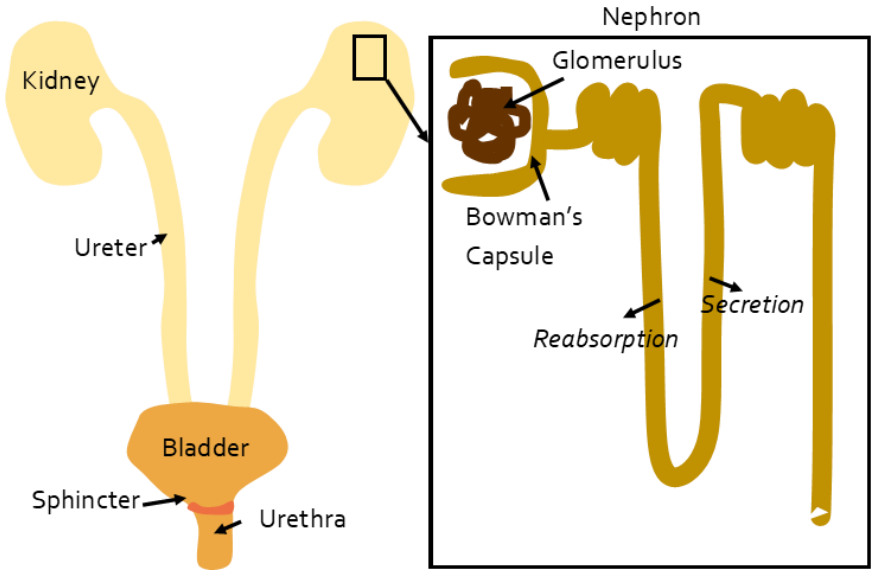
Excretory System

The main function of the excretory system is to remove liquid wastes from the body, including not just water, but also salt, carbon dioxide, and any possible toxic materials. The most important part of this system is the **urinary system,** which is what gets rid of most of the waste.

The urinary system starts with the **kidneys**, which where blood from the circulatory system will enter. Within the kidneys are things called **nephrons**, and there are many of them within a single kidney (you have two total kidneys). Inside a single nephron, as blood gathers

within a bunch of capillaries called the **glomerulus**, the fluid portion will eventually exit the capillaries and into something called the **Bowman's capsule**. There the fluid portion of the blood is now called **filtrate,** and the process in which this occurred is known as **filtration**. Then, the filtrate will travel through a long tubule, where the nutrients that need to be kept by the body are taken back into the blood (through the very small capillaries) in a process called **reabsorption**, and waste materials that the body no longer needs from the blood enter into the tubule, a process called **secretion**. What remains in the filtrate now becomes the **urine**, and it travels out of the nephrons and the kidneys.

This urine will now enter through tubes called the **ureters** and will be gathered at the **bladder.** Rather than being immediately excreted, however, the **sphincter** blocks it until the bladder is filled. Then, the urine will exit the body through the **urethra.**



Topic 5.4 Integumentary and Immune

The integumentary system is essentially the parts of the body that we can see and interacts with many other systems. One notable interaction it has is with the immune system, which helps to protect our bodies from diseases, as well as make sure past diseases cannot reappear within our bodies.

Integumentary System

The functions of the integumentary are what you might expect for being exposed to the outside. It protects our internal organs from anything that might be harmful to them, including ultraviolet lights, bacteria, and toxic materials. In addition, it maintains a constant temperature for our body, as well as gets rid of wastes.

Parts of the integumentary include the skin, but also includes our hairs and our nails. Within our skin, there are three layers. The top layer, or the **epidermis**, is the part of the skin that we see and is actually the thinnest of the three layers. The middle layer or the **dermis** is much thicker and contains the **hair follicle**, which is the origin of where hair growth starts and eventually goes outside. Within this section also exists **sweat glands**, which create sweat, to cool down the body, maintaining homeostasis when you get too hot. This is an example of how the integumentary system works with the excretory system. Also, there are **oil glands** that secrete oils. Finally, the bottom layer, or the **hypodermis**, stores fat with **adipose** cells which creates adipose tissues.

Immune System

The way that our body protects itself is broken down into two different types of defense: **nonspecific defense** and **specific defense**. Specific defense is the type of defense that actually makes up the immune system, but we will also cover the types of nonspecific defense.

The body has two different mechanisms of nonspecific defense. Nonspecific means that it is a general type of defense that does not cater to a certain **pathogen**, something that can cause disease.

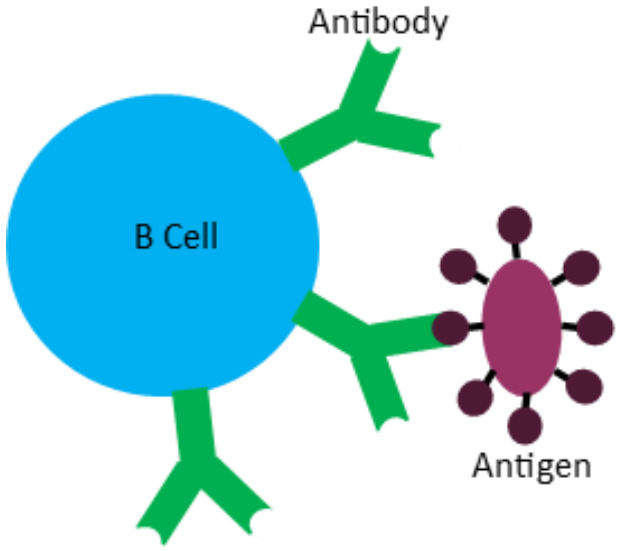
The first type of nonspecific defenses consists of barriers. This includes the skin or the integumentary system. The skin can protect against invaders with sweat glands, as well as other oils that the skin produces. Barriers do not have to be on the outside to protect us, however. **Mucous membranes** are membranes found in tracts throughout the other body systems, and they can secrete things such as **lysozymes**, which break down bacteria, and mucus, which traps the invaders. Also found in the body are small hair-like linings called cilia as well as acids such as gastric juices which can eliminate invaders.

If the pathogen can get through the 1st layer of nonspecific defense, it is met with another form of nonspecific defense, known as internal defenses. One type of internal defense is the **leukocyte**, or the white blood cells found in the circulatory system. One type of leukocyte is the **phagocyte**, which swallows up any pathogen it can. Phagocytes include **macrophages**,

which are large pathogen-eaters. Another type of leukocyte is the **Natural Killer Cell** or the NK cells. These will kill cells that contain viruses to prevent the virus from spreading onto other cells. Leukocytes know to travel to the location where a pathogen has entered the body due to the **inflammatory response.** This is because leukocytes produce something called **histamine** whenever it finds a pathogen. This will then send a signal to the phagocytes to go and consume these invaders, as well as cells that contain pathogens.

The third type of immune response is the specific type, meaning it targets a certain pathogen, whether it be a bacteria, virus, or something else. One example of specific defense is with **lymphocytes**, which consist of two different types. **B lymphocytes** and **T lymphocytes**, which differ in the places that they mature: B lymphocytes mature in the bone marrow while the T lymphocytes mature in the thymus. Lymphocytes are usually stimulated by the macrophages, and they are specific because they can recognize specific **antigens**, which is anything foreign to the cell. When B lymphocytes are exposed to antigens, it will secrete **antibodies**, y-shaped molecules which will attach with an antigen like a lock-and-key. This will essentially "tag" the antigens and mark them so other cells know that it is bad. Remember that antibodies can also be referred to as **immunoglobins.** T lymphocytes, on the other hand, are divided into cytotoxic T cells and helper T cells. **Cytotoxic T Cells** kill pathogens by killing the cells with them, while **Helper T Cells** aid other lymphocytes with their functions. Lymphocytes are extremely helpful,

especially if the body that received a pathogen receives it again later in life. For example, the B cell/lymphocyte will create copies of itself after the first exposure called **memory B cells**, and when the body is exposed the second time, the body already has the antibodies ready to be produced to combat the pathogen.



Topic 5.5 Endocrine and Reproductive

For the body to regulate certain functions by itself, it relies on the endocrine system to send chemical messages throughout the blood. The things produced in the endocrine system can also aid in the processes in the reproductive system.

Endocrine System

The endocrine system consists of many **glands**, which produce **hormones**, which are chemical messages that affect events in our bodies. The two classes of hormones are **steroid** and **nonsteroid**. Steroids, as you may remember, are types of lipids, meaning they can pass through the cell membranes of cells. Therefore, steroid hormones can directly bind to parts inside the cell and affect its function. Nonsteroid hormones, on the other hand, are made of proteins and cannot pass through the cell membrane. As a result, they will bind with receptors found on top of the cell membrane and sends a message into the cell for a change to take place.

The most important gland in the endocrine system is the **pituitary gland** because its job is to control all the other glands in the human body. The hypothalamus in the brain is responsible for controlling the pituitary gland.

Some roles that the hormones produced by the pituitary gland have include stimulating cell growth, the thyroid gland, the adrenal gland, the ovaries, testes, the production of breast milk, contraction during childbirth, and water retention.

The **thyroid gland**, which secretes the hormone **thyroxine**, helps in stabilizing metabolic rates. It also produces **calcitonin**, which lowers the amount of calcium in your blood when it gets too high and uses it to make bones. The **parathyroid gland**, on the other hand, does

the opposite, and releases calcium to the bloodstream as needed, helping in things such as blood clotting.

The **adrenal gland** secretes hormones that stimulate the "fight-or-flight" response within humans (**adrenaline**), as well as steroid hormones. The **pineal gland** makes and secretes the hormone **melatonin**, which regulates cycles that the human body undergoes.

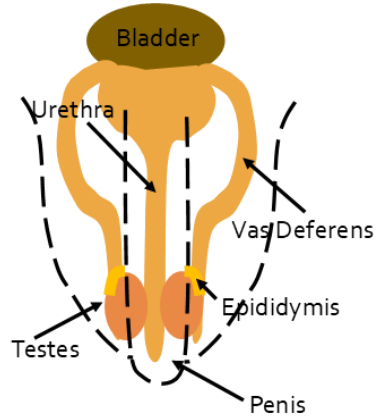
The **pancreas**, also found in the digestive system, has the endocrine function of secreting **insulin** to lower blood glucose levels when they are too high, as well as secreting **glucagon** to increase blood glucose when it is too high. This cycle and regulation are known as a **negative feedback loop**, where if the body needs something, it will produce more, but if the body does not need it, it will produce less. This contrasts with a **positive feedback loop**, which will consistently provide more of something during a process. A positive feedback loop is observed during childbirth, where hormones will continue muscle contractions in the uterus until the baby is born.

Two final glands in the body are the **testes** in males and the **ovaries** in females. Testes will produce the hormone **testosterone** which will help to produce sperm and stimulate manly characteristics, while ovaries will produce **estrogen** and **progesterone** which will help in the reproductive system.

Gland	Location
Pituitary	Brain
Thyroid	Throat-Area
Parathyroid	Resting on top of Thyroid
Adrenal	Resting on Kidneys
Pineal	Brain
Pancreas	Next to Stomach
Testes	Males Only
Ovaries	Females Only

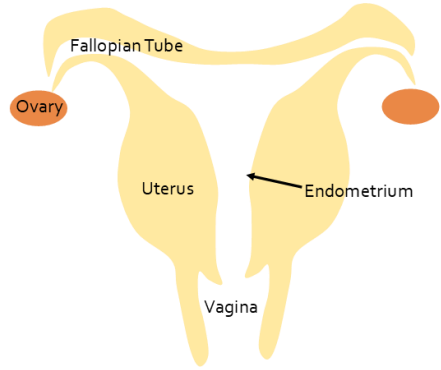
Reproductive System

The job of the reproductive system is to produce gametes, which are the sperm in males and the eggs in females. When the two gametes are fertilized, it produces a zygote and will grow in the female.



Males: Sperm is created by testosterone in the **seminiferous tubules,** which is part of the testes. The sperm then travels to the **epididymis** and then will travel

through the sperm duct known as the **vas deferens.** The sperm will mix with a fluid to produce **semen**, and will eventually exit through the **urethra** and the **penis,** where it will enter a female's vagina for fertilization.



Female: The female reproductive system focuses on the eggs, which are produced in the ovary of a female. During **ovulation,** which occurs once a month, an egg will travel out of the ovary and into a fallopian tube. If a sperm is available to fertilize it, it will then travel down to the **uterus** and will attach to the wall of it, called the **endometrium.** The zygote that is made will eventually grow into a fetus, and after about 9 months, the baby will leave through the vagina, and childbirth occurs. If the egg is not fertilized, however, the monthly cycle will repeat in a process called the **menstrual cycle.** Many hormones are involved in the menstrual cycle. For example, the follicle-stimulating hormone and the luteinizing hormone made by the pituitary gland oversee ovulation and secreting other types of hormones including estrogen and progesterone. These two hormones have the role of building up the uterine lining in case fertilization occurs.

Unit 5 Vocabulary Terms

Accessory Organs
Actin
Adipose
Adrenal Gland
Adrenaline
Alimentary Canal
Alveoli
Amylase
Antibody
Antigen
Anus
Aorta
Aortic Semilunar Valve
Appendicular
Artery
Atrium
Axial
Axon
B Lymphocyte
Ball-and-Socket Joint
Bicuspid Valve
Bile
Bladder
Bowman's Capsule
Bronchi
Bronchiole
Calcitonin
Capillary
Cardiac Muscle
Cartilage
Cartilaginous Joint
Central Nervous System
Cerebellum
Cerebrum
Chemical Digestion
Chyme
Compact Bone
Connective Tissue
Cytotoxic T Cell
Dendrite
Dermis
Diaphragm
Endocrine System
Endometrium
Epidermis
Epididymis
Epithelial Tissue
Erythrocyte
Esophagus
Estrogen
Excretory System
Filtrate
Filtration
Gallbladder
Gastrointestinal Tract
Gland

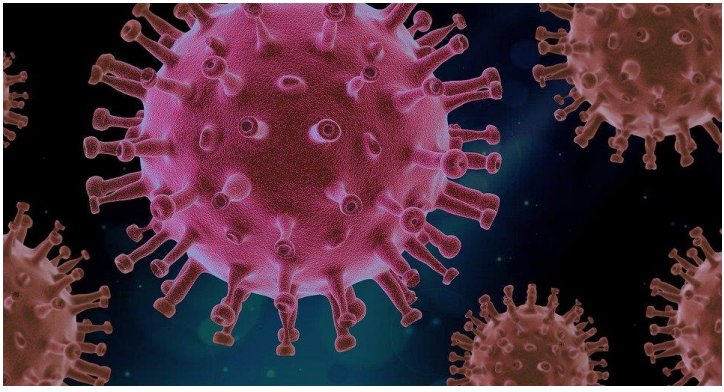
Glomerulus
Glucagon
Hair Follicle
Helper T Cell
Hemoglobin
Hinged Joint
Histamine
Homeostasis
Hormone
Hypodermis
Hypothalamus
Immovable Joint
Immune System
Immunoglobin
Inflammatory Response
Insulin
Integumentary System
Involuntary Muscle
Joint
Kidneys
Large Intestine
Larynx
Leukocyte
Leukocyte
Ligaments
Liver
Lungs
Lymphocyte
Lysozyme
Macrophage
Mechanical Digestion
Medulla
Melatonin
Memory B Cell
Menstrual Cycle
Microvilli
Motor Neuron
Mucous Membrane
Muscle Tissue
Muscular System
Myosin
Natural Killer Cell
Negative Feedback Loop
Nephron
Nerve Impulse
Nervous System
Nervous Tissue
Neuron
Neurotransmitter
Nonspecific Defense
Nonsteroid
Oil Gland
Ovaries
Ovulation
Pancreas
Parathyroid Gland
Pathogen
Penis
Pepsin
Peripheral Nervous System
Peristalsis

Phagocyte
Pharynx
Pineal Gland
Pituitary Gland
Plasma
Platelet
Positive Feedback Loop
Progesterone
Pulmonary Artery
Pulmonary Circuit
Pulmonary Semilunar Valve
Pulmonary Vein
Reabsorption
Rectum
Reproductive System
Respiration
Sarcomere
Secretion
Semen
Semi-Mobile Joint
Seminiferous Tubule
Sensory Neuron
Skeletal Muscle
Skeletal System
Small Intestine
Smooth Muscle
Specific Defense
Sphincter
Spongy Bone
Steroid
Stomach
Sweat Gland
Synapse
Synovial Joint
Systemic Circuit
T Lymphocyte
Tendon
Testes
Testosterone
Thyroid Gland
Thyroxine
Trachea
Tricuspid Valve
Ureter
Urethra
Urethra
Urinary System
Urine
Uterus
Vas Deferens
Vein
Vena Cava
Ventricle
Villi
Voluntary Muscle

UNIT 6: TAXONOMY

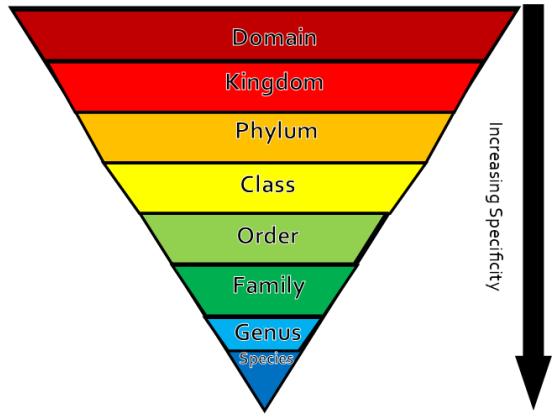
- 6.1 Organization and Viruses
- 6.2 Bacteria, Archaea, Fungi
- 6.3 Protists
- 6.4 Plants
- 6.5 Animals

Topic 6.1 Organization and Viruses



Carl Linnaeus was a scientist best known for his work in classifying all living things into different groups based on certain traits they share. This system became known as taxonomy. After covering the basics, we will talk about the virus, which is outside the classification of living things.

Taxonomy is essentially the way organisms are organized. As the taxonomic group goes from broad to specific, it narrows down the type of organism until eventually, there is only one species left. When two organisms share more taxonomic groups, they are more similar to one another



The broadest group of taxonomy is the **Domain**. There are three major domains, Bacteria, Archaebacteria, and Eukarya. Both the bacteria and archaebacteria have one **Kingdom** each, those being Eubacteria (or just Bacteria) and Archaebacteria (basically the same as the domain name). The Eukarya domain is split into four different Kingdoms, being Protista, Fungi, Plantae, and Animalia. In order of most specific to least specific, following the Kingdom is Phylum, Class, Order, Family, Genus, and Species. The final two, the Genus and the Species are used in the **Binomial Classification System**. This, created by Linnaeus, was a method of assigning every organism a specific two-part name based on its most specific taxonomic groups.

Quick Tip:
One of the most common ways to memorize the taxonomic groups is by the phrase "Dear King Phillip Came Over For Good Spaghetti", using the first letter of each word as a representation of a taxonomic group.

Although taxonomy has been useful in classifying and naming living organisms, **viruses** cannot be organized through taxonomy. This is because to be a living organism, it must be made out of cells and provide its own resources to grow. Viruses are made up of neither prokaryotic nor eukaryotic cells, and in fact, are smaller than either. The structure of a virus, in fact, is only nucleic acids such as DNA and RNA surrounded by a protein coat called a **capsid**. Furthermore, viruses depend on a **host** in order to grow to reproduce, meaning it relies on another living organism to replicate its DNA and make copies of itself. There are two cycles that a virus follows to reproduce.

To provide an example of how these cycles work, I will introduce you to the **T2 Bacteriophage**. This virus specifically attaches to bacteria using a lock-and-key fit, meaning it is specific to certain types of bacteria. It can act as a pathogen and can multiply quickly by depending on the normal replication of bacteria. In the **lytic cycle**, the bacteriophage will begin by attaching to the bacteria. Then, it will inject its own genetic code (in this case, DNA) into the host cell. With the processes of DNA replication and Protein Synthesis, the virus can create the two components that it needs to make a new bacteriophage:

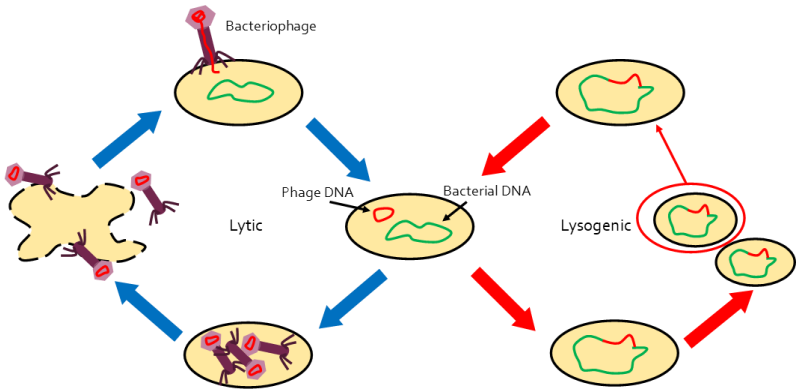
genetic material and a protein capsid. In fact, many copies of the T2 bacteriophage will be assembled within the bacteria cell. Eventually, the cell will lyse, breaking down the cell membrane and allows the new viruses to escape from the cell and infect other bacteria.

The **lysogenic cycle** is an alternative way to expand the numbers of a virus. In this cycle, after the bacteriophage has inserted its DNA code into the bacteria, it will join with the DNA of the bacteria. This new DNA code, containing information for both the bacteria and the virus, is called a **prophage.** Like all DNA, it will replicate, and like all cells, the Bacteria will undergo mitosis, splitting into two identical copies, each containing the prophage. After many cell divisions, there will be a large population of bacteria that hold the DNA of the T2 bacteriophage. For the lysogenic cycle to end, the cell must undergo the lytic cycle, creating bacteriophages and causing them to eventually escape. Therefore, while the lysogenic cycle can create copies of the genetic code, it is actually the lytic cycle that will make the new viruses.

Did you know?

The reason why antibiotics are ineffective against viral diseases is that viruses are not living organisms. To treat diseases caused by viruses, we use antivirals.

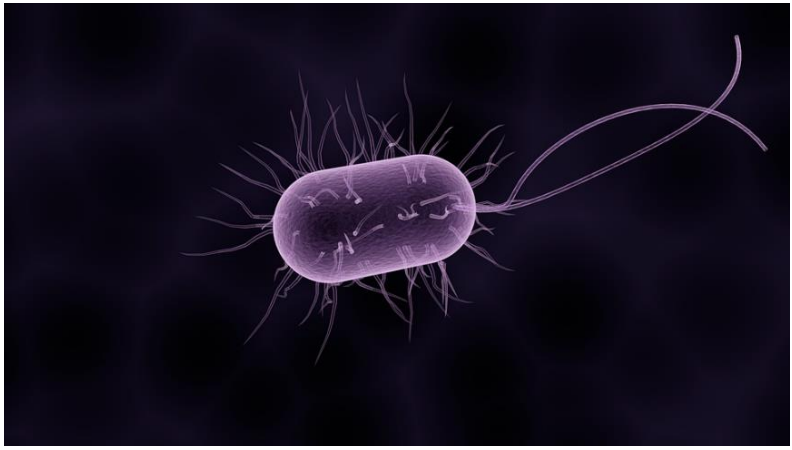
Some viruses, such as the HIV Virus, do not contain DNA, but instead, have RNA as their genetic material. For the RNA to join with the DNA code of a host cell, it has to be converted into DNA. To do this, it will use an enzyme called **Reverse Transcriptase**. It is called reverse because rather than following the Central Dogma of biology and using DNA to convert to RNA, it does the opposite. For this same reason, viruses like HIV are known as **retroviruses**.



Here is a short list of the different shapes of viruses, which is the main way viruses are classified.

- Helical: This shape is a hollow cylinder. An example of this is the Tobacco Mosaic Virus or TMV.
- Polyhedral: Viruses such as the adenovirus, which cause the common cold, are a geometric 3-D figure with many sides.
- Spherical: The most well-known spherical virus is the influenza virus, which causes the flu.
- Binal: Viruses like the T2 bacteriophage do not have a specific shape, and usually have a complex structure.

Topic 6.2 Bacteria and Archaea



Both Bacteria and Archaea have their own Domain and Kingdoms, but they are both very similar to one another, notably because they both have prokaryotic cells only. However, they are categorized in two different domains because of a few key differences.

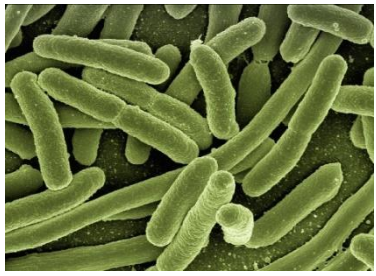
Bacteria

The structure of a bacteria has already been presented in the section discussing the cell parts of a prokaryotic cell. Therefore, you should know that a bacterium contains circular DNA, no nucleus, no membrane-organelles, but does have a cell wall and a cell membrane, as well as ribosomes to make proteins. Bacteria all are single-celled organisms, but they vary in the method in which they obtain food. Some are **autotrophs**, meaning they can produce their own food. Examples of these are **photoautotrophs** which depend on light in order to obtain energy and **chemoautotrophs** which get food from chemical compounds. Others are **heterotrophs**, meaning they rely on other organisms for energy. Some examples are pathogens, which cause disease.

Bacteria are classified based on two factors: their shape and the quantity that they are found in. The three shapes of bacteria are **Coccus** (spheres), **Bacillus** (rods), and **Spirillum** (spirals). The three varying quantities are **Diplo-** (pair), **Strepto-** (chain), and **Staphylo-** (Cluster). For example, if you had a Spherical shaped bacterium that came in a long chain, it would be called Streptococcus.

While we usually think of bacteria as bad and causing diseases, this is not always the case. While it is true that some bacteria can harm humans and need to be prevented with antibiotics, some bacteria can actually be beneficial. One example of bacteria helping other

organisms is **E. coli**, which helps humans in digestion by living in the gut.



Archaea

Archaea, as stated before, are very similar to Bacteria; they both are unicellular, reproduce by binary fission, and can get energy by their own means or by relying on other organisms. However, the difference between them is the composition of their cell walls, with bacteria having a substance called **peptidoglycan** in their cell walls, while archaea do not. Another main difference is where they are found. Archaea are commonly found in extreme environments, such as **halophiles** living in extremely salty conditions, **thermophiles** living in extremely hot conditions, and **methanogens** living in methane, a substance toxic to humans. Bacteria, on the other hand, can be found anywhere.

Thermophiles will live in hot springs like the image shown here.

Genetic Variation

Even though prokaryotes reproduce asexually and can only create identical prokaryotic offspring, there is a way for bacteria and archaea to exchange their DNA to have genetic variation. The first type, **transformation**, involves a bacterium taking up DNA from its surroundings. One way this occurs is when one bacteria lyses, it releases its genetic material into another bacteria, and the DNA recombines. Another way bacterium can receive foreign DNA is through **transduction**, which is the reception of DNA from a virus, which carries DNA from one bacterium to another. A prominent example of this is bacteriophages. Finally, two bacteria can actually contact each other, and in a process called **conjugation**, DNA is transferred from one cell to another.

Did you know?

One way conjugation has been used by scientists is through plasmids, which are short segments of DNA that humans can introduce into a certain bacteria. Because that bacteria can transfer its plasmids to another cell, as well as replicate itself, it can create many copies of that plasmid, which scientists can then use to do data analysis.

Topic 6.3 Fungi and Protists

Both Fungi and Protists are Eukaryotic Organisms and they both are included in the Kingdom Eukarya. Fungi, while most will think just include things such as mushrooms, actually have a vast array of species. Protists also vary widely, with a large number of protists having little characteristics in common with each other.

Fungi

All fungi are eukaryotic, but they can either be multicellular or unicellular. An example of a unicellular fungus is yeast. They are **decomposers,** meaning they obtain nutrients by breaking down other organisms and absorbing their nutrients. Also, they have a cell wall made of chitin.

Fungi can reproduce either sexually or asexually. One method of reproduction is by using spores. Each fungus can produce extremely large amounts of spores, and if a spore is able to find a satisfactory spot to gather nutrients, it will grow to become its own fungi. Fungi such as yeast can reproduce asexually through a process called **budding.**

Yeast is used in helping things like bread rise.

There are four phyla of fungi. One phylum, Zygomycota, consists of molds and **mycorrhizae**. This is an example of a mutualistic fungus, which helps legumes (a type of plant including peas and beans) receive nitrogen in a usable form. Another phylum, Basidiomycota, is known as club fungi and consists of the edible fungi that we usually think of when we hear of the word "fungi", including mushrooms and puffball.

Protists


Mycorrhizae

As stated before, protists are also eukaryotic and can either be multicellular or unicellular. Some lack a cell wall, while others contain one made of cellulose. Protists are can somewhat be thought of as the "leftover" kingdom since each organism within this classification has little in common besides a few traits. As a result, scientists like to classify protists by the similarities it has with other kingdoms, such as animals, plants, and fungi.

Did you know?

Protists contrast the other Eukaryotic Kingdoms because it is monophyletic, meaning they do not all originate from a common ancestor. Therefore, protists are often referenced to as an artificial group.

Protists that are similar to animals are referred to as **protozoa**. They are like animals because they are heterotrophic, relying on other organisms for energy, specifically by ingesting them. Protozoa can be categorized based on the manner that they move. **Amoebas**, for example, use **pseudopodia**, which are protrusions around the cell that it cannot only use for movement, but also for ingestion.

Ciliates and **Flagellates** use cilia and flagella, respectively, to travel around. Recall that cilia are the small, hair-like projections around the cell, while a flagellum is a long, whip-like structure at one end of the cell. One example of a ciliate is a paramecium, while an example of a flagellate is a euglena. Another type of protozoan is the **sporozoan**, which includes the protist plasmodium, which causes malaria. Like plasmodium, all sporozoans are parasites, meaning it harms another organism to benefit itself.

Algae tends to live in moist

Plant-like protists are referred to as **Algae**. While you may have heard of this word and thought that it was a type of plant, it is actually a photosynthetic protist that receives its own food. Because of this, protists can either be heterotrophic or autotrophic, and some can even be both. For example, **euglenoids** can photosynthesize in the presence of the right resources, but when it lacks things such as light, it can consume food like protozoa. However, more traditional algae will only photosynthesize. They can be small and unicellular, like the **phytoplankton**, or can be large and multicellular like **brown algae**, also known as seaweed. Other types of algae are listed here:

Seaweed, or brown algae, is a one of the larger protists out there.

- **Diatoms** have glass-like walls that can deposit diatomaceous earth when they die, which can be utilized for filtering.
- **Dinoflagellates** are known to cause human illnesses such as shellfish poisoning and contribute to events such as red tides, where a large number of algae in the sea bloom due to large amounts of nutrients after storms.
- **Red algae** are able to live in deeper waters than most amoebas.
- **Green algae** mostly live in freshwater and live close to the surface. As a result, we can see them when the tides go down.

Topic 6.4 Plants

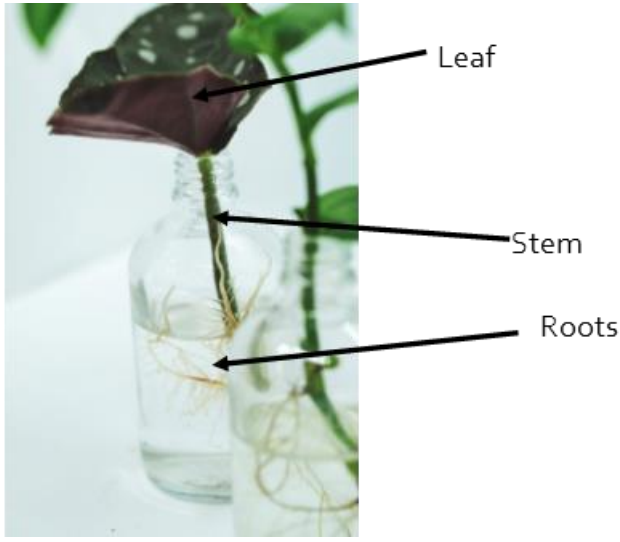
The Kingdom Plantae consists of eukaryotic organisms, all of which are multicellular and are unable to move. They also share the trait that can photosynthesize, meaning they are photoautotrophic, and they also have cell walls made of cellulose. Unlike animals, plants are nonmotile, meaning they cannot move through their own means.

Plant Parts

Things that help plants to stand out from the other kingdoms are their roots, stems, and leaves. Let's go more in-depth on each one.

The function of a root is to keep the plant from losing access to its resources by anchoring it into the earth. They can also take in the water and nutrients that their environment has, such as the soil after rainfall. To maximize the nutrients it receives, it increases its surface area with root hairs, small protrusions on top of the root.

The main priority of a stem is to provide structure to



the plant to keep it from falling over. In addition, it helps to transport materials from the roots to the rest of the plant. For example, within the roots are **xylem**, which carries liquids like water upwards, while **phloem** transports food like glucose up and down the plant. Some stems are small, while others can be thick and woody like those in trees.

Leaves are the site where photosynthesis occurs. The gases that enter and exit the leaves do so through stomata, which are small openings that are all over the leaf. The top layer of a leaf has a waxy covering called a **cuticle**, which better retains water for the plant. Under the cuticle is the epidermis, which has the mesophyll inside it, the site of photosynthesis.

Cuticles are located on top of leaves and help water retention.

Tropisms

Tropism is the movement of a plant in response to a stimulus that happens in the external environment. Depending on the type of tropism, plants will respond accordingly to maximize their nutrient and light access. Tropisms occur due to hormones specific to plants called **auxins.** Positive tropisms are those that cause the plant to move towards the stimulus, while negative tropisms cause plants to move away from the stimulus.

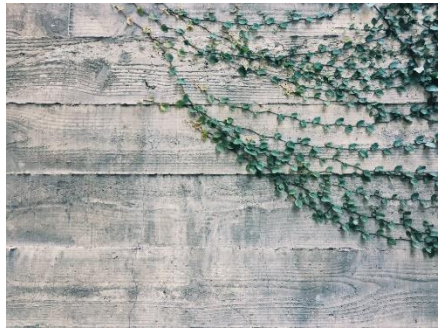
Gravitropism is where parts of a plant, such as roots, will succumb to the force of gravity, growing downwards. This is known as positive gravitropism since it moves towards the force of gravity. When a plant's stems grow upwards, it is called negative gravitropism since it goes against gravity. Gravitropism is also referred to as geotropism, with the stem geo- meaning earth.

Phototropism is the inclination for a plant to grow towards the light. This is most common with sunlight and its rays hitting the plant at a certain location.

See for yourself!

If you grow a houseplant at the side of a window, you may see that the plant will lean towards the window as it grows. This is because it is better able to reach the light and photosynthesize more efficiently.

Thigmotropism is where plants will respond to physical contact with the plant. An example of this is certain plants coiling up a cylinder as it grows upwards for support, or a vine attaching to walls.



Vines like this one attach to the walls and respond to touch, making it an example of thigmotropism.

Classification

The first plant to exist was likely very basic, with little resembling the complex trees and flowers that we see today. As evolution occurred over time (a concept we will explore later), more advanced plants branched out from that original plant, and we eventually got to the diversity that we see today. Because of this, scientists can categorize plants based on when they received a certain trait.

The first split in the evolutionary history of plants is the development of vascular vessels to transport nutrients. Plants that are nonvascular are called **bryophytes**, and they must gain water through processes like osmosis. Because of this, they must live in moist environments where water is plentiful to absorb. Examples of bryophytes are mosses and liverworts.

The vascular plants can then be split between those that do not produce seeds to reproduce and those that do. Plants that do not reproduce using seeds are called **pteridophytes**, and they instead use **spores**¸ which can be dispersed by the environment such as wind and water. Examples of seedless vascular plants include ferns.

Plants with seeds utilize them to protect the embryo and help it to grow with nutrients. Among plants that have seeds, they are divided based on the type of seeds they have. Plants that have seeds without a protective coat are called **gymnosperms**, and their seeds are sometimes referred to as "naked" since they are often exposed to the outside environment. Instead of a covering, the seeds of gymnosperms can be found on cones, such as in conifers and cycads.

Finally, vascular plants that have seeds with a sealed covering are called **angiosperms**. The protective covering can be things such as fruits or nuts, and examples of these are plentiful, such as apples and lima beans. There are two main types of angiosperms: **monocots** and **dicots**. Some of their differences are listed here.

Monocot	Dicot
One Cotyledon*	Two Cotyledons
Floral Parts in multiples of 3	Floral Parts in multiples of 4 or 5
Leaves have parallel veins	Leaves have netlike veins
Vascular bundles in the stem are scattered	Vascular bundles in the stem are in a circle

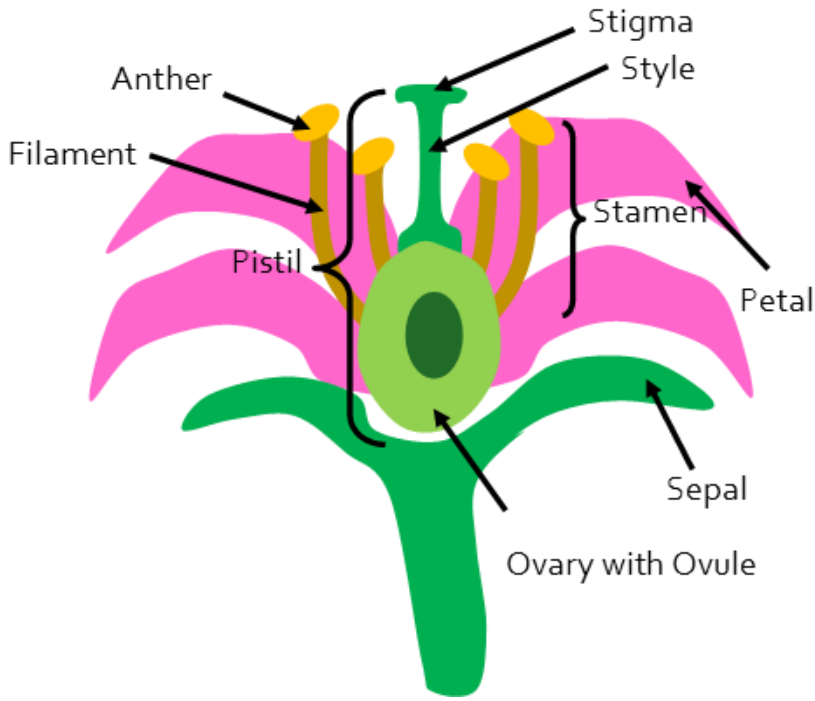
Fibrous Root System, does not have a central root.	Taproot System, contains a central vertical root with smaller roots extending from it.

*a **Cotyledon** is, in simple terms, the first leaf/pair of leaves in a plant embryo.

Plant Reproduction

Angiosperms contain both a male part and a female part. The male part is called the **stamen,** and its job is to produce **pollen,** which can be used to fertilize the female part of the plant or the **pistil.** The stamen is separated into two parts: The **filament** is the stalk that supports the other part, which is the **anther.** The anther is the part that actually produces the pollen. Pollen can pollinate with the help of external forces, including pollinating animals. Plants attract pollinators with petals. Once the pollinators can take the pollen and carry it to a plant's pistil, a plant embryo can be made. A pistil is divided into three parts. The **stigma** is a sticky top layer where pollen is supposed to travel onto. The thing that supports it is called the **style.** After the pollen germinates, a pollen tube will grow down the style, and two sperms from the pollen will enter the final part of the pistil; the **ovary,** which contains an **ovule**. In the ovary, one sperm will fertilize the egg, making a plant **embryo,** while the other sperm will combine with polar bodies (the small remaining cells created after meiosis after the main oocyte essentially takes its nutrients) and forms the

endosperm, which provides nutrients for the embryo. The ovule will become the seed of the plant, while the ovary will become the fruit. Another part of the plant is the **sepal,** a leaflike part that protects the plant while it buds and supports the petals.

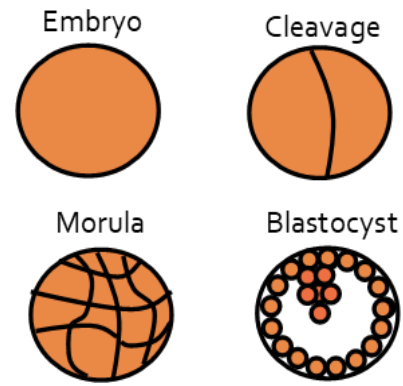


Topic 6.5 Animals

The Kingdom Animalia is part of the Domain Eukarya, and like plants, all the organisms are multicellular. Contrasting plants, however, is the fact that they do not have cell walls, as well as their method of consuming nutrients. Animals are all heterotrophic, and are mobile, meaning they are capable of movement. They also reproduce sexually, requiring a female and a male.

Development:

After the gametes are formed in meiosis, the sperm from the male must fertilize the egg of a female for a zygote to form. This zygote will have 46 chromosomes, with 23 coming from each parent. The next step is for the zygote to undergo **cleavage**, where the cell will undergo rapid mitosis. One cell will become two, two will become four, four will become eight, and this process will continue until a ball of cells called a **morula** is formed. However, this ball will retain its size as the original zygote. Then, the morula will bind to the uterine lining of the female. As it does this, a **blastocyst** forms as the circular shape hollows out, creating an outer sphere and an inner cell mass. Then, an **embryo** is formed as the embryonic stage starts. This is where the inner cell mass, a cluster of cells inside the hollow sphere, will divide into three sections: the **endoderm** will eventually form parts of the digestive and respiratory system, the **mesoderm** will make up the skeletal system, the cardiovascular system, the reproductive system, and excretory system, and the **ectoderm** will form the integumentary and nervous system. Eventually, the embryo will grow into a **fetus** and will mature until birth happens.



Animal Diversity

The first way that animals can be differentiated is by the type of symmetry they have. Some are asymmetrical, without any regular shape. Some are radial, meaning that their body surrounds a central axis. Finally, some are bilateral, meaning they are separated into two sides. In addition, some animals have **cephalization**, which is where the sensory organs of organisms are located in one central location.

Another way to differentiate between animals is the presence of a body cavity to hold organs. **Acoelomates** lack a body cavity. **Pseudocoelomates** have a "false cavity. **Coelomates** have a true body cavity, protecting these animals during movement. Some animals are segmented, meaning they are made up of repeated units.

The presence of advanced body systems can vary. For example, for respiration, animals living in water rely on gills, which are projections of tissue, while animals living on land rely on lungs. Those with neither depend on diffusion for respiration. Another body system variation is the circulatory system. An open circulatory system means that the fluids pumped from the heart come in direct contact with tissues. On the other hand, a closed system uses vessels and relies on diffusion.

Different animals also have varying support structures. Some have a **hydrostatic** skeleton, which is made of water in a pressured cavity. Others have an **exoskeleton**, which is an external casing on the animal,

while animals with an **endoskeleton** have support on the inside of the body. The way an animal excretes waste, whether it be solid, liquid, or gas, can vary. Some use diffusion, and animals like humans use kidneys to filter and regulate wastes. Finally, the way animals reproduce varies. While all animals can reproduce sexually, some can asexually create copies of themselves through **budding**. Also, some animals are **hermaphrodites**, meaning they have both the testes of males and the ovaries of females.

The different animal phyla can be summarized in this chart. You do not have to memorize this entire chart, but it does help you to get an idea of the main difference between different animals.

Phylum Name	Porifera	Cnidaria
Common Name	Sponges	Coelenterates
Examples	Sycon, Spongilla	Hydra, Jellyfish
Body Symmetry	Asymmetric	Radial
Cephalization	No	No
Body Cavity	Acoelomate	Acoelomate
Segmentation	No	No
Respiratory System	None	None
Circulatory System	None	None
Support	Endoskeleton	Hydrostatic
Excretion	None	None
Reproduction	Sexual/Asexual	Sexual/Asexual
Other facts	Sessile (Nonmoving)	

Phylum Name	Platyhelminthes	Nematoda
Common Name	Flatworms	Roundworms
Examples	Flukes, Tapeworms	Hookworms, Whipworms
Body Symmetry	Bilateral	Bilateral
Cephalization	Yes	Yes
Body Cavity	Acoelomate	Pseudocoel
Segmentation	No	No
Respiratory System	None	None
Circulatory System	None	None
Support	None	Hydrostatic
Excretion	Canals	Glands
Reproduction	Sexual/Asexual	Sexual + Hermaphrodite

Phylum Name	Annelida	Mollusca
Common Name	Segmented Worms	Mollusks
Examples	Earthworms, Leeches	Snails, Octopus
Body Symmetry	Bilateral	Bilateral
Cephalization	Yes	Yes
Body Cavity	Coelom	Coelom
Segmentation	Yes	No
Respiratory System	None	Gills or Lungs
Circulatory System	Closed	Open
Support	Hydrostatic	Shells

Excretion	Nephridia	Nephridia
Reproduction	Sexual + Hermaphrodite	Sexual + Hermaphrodite
Other facts		Contain three parts; foot for movement, visceral mass for organs, mantle for shell

Phylum Name	Arthropoda	Echinodermata	Chordata
Common Name	Arthropods	Echinoderms	Chordates
Examples	Crustaceans, Arachnids, Insects	Sea Stars, Sea Urchins	Fish, Mammals, Birds
Body Symmetry	Bilateral	Radial	Bilateral
Cephalization	Yes	No	Yes
Body Cavity	Coelom	Coelom	Coelom
Segmentation	Yes	No	Yes
Respiratory System	Gills or Lungs	Tube Feet	Gills or Lungs
Circulatory System	Open	None	Closed
Support	Exoskeleton-Chitin	Exoskeleton	Endoskeleton
Excretion	Glands	None	Kidneys
Reproduction	Sexual	Sexual/Asexual	Sexual
Other facts	Most Diverse		*See Below*

Sponge

Coelenterate

Seqmented

Mollusk

Arthropod

Echinoderm

Chordata

Chordates

The phylum Chordata is the one that humans are classified in. The major similarity between all chordates is that they have a backbone, and thus are known as **vertebrae.** All other animals lack this backbone and are called **invertebrates.** Here are the main classes of chordates, in the order that they evolved.

Chondrichthyes and Osteichthyes are both classes for fish, representing fish with cartilage and bones, respectively. Fish with cartilage include sharks, while fish with bones include bass and tuna.

Amphibia is a class consisting of amphibians, animals that can live on both land and water. The primary example of this is the frog.

Class Reptilia contains reptiles that are cold-blooded, or **exothermic**, and have scaly skin to retain water. Examples include lizards, snakes, and alligators.

Class Aves includes birds, which are warm-blooded, or **endothermic.** They are unique for their possession of wings. Examples include penguins and cardinals.

Class Mammalia is the class that humans are in. Mammals are similar because they bear live young, are endothermic, and have hair.

Unit 6 Vocabulary Terms

Acoelomate
Amoeba
Angiosperm
Anther
Archaea
Autotroph
Auxin
Bacillus
Bacteria
Binomial Classification System
Blastocyst
Brown Algae
Bryophyte
Budding
Capsid
Cephalization
Chemoautotroph
Chordate
Ciliate
Cleavage
Coccus
Coelomate
Conjugation
Cotyledon
Decomposer
Diatom
Dicot
Dinoflagellate
Diplo-
Domain
Ectoderm
Embryo
Endoderm
Endoskeleton
Endothermic
Euglenoid
Exoskeleton
Exothermic
Fetus
Filament
Flagellate
Fungi
Gravitropism
Green Algae
Gymnosperm
Halophile
Hermaphrodite
Heterotroph
Host
Hydrostatic
Invertebrae
Kingdom
Lysogenic Cycle
Lytic Cycle
Mesoderm

Methanogen
Monocot
Morula
Mycorrhizae
Ovary
Ovule
Peptidoglycan
Phloem
Photoautotroph
Phototropism
Phytoplankton
Pistil
Pollen
Prophage
Protist
Protozoa
Pseudocoelomate
Pteridophyte
Red algae
Retrovirus
Reverse Transcriptase
Sepal
Spirillum
Spore
Sporozoan
Stamen
Staphylo-
Stigma
Strepto-
Style
T2 Bacteriophage
Taxonomy
Thermophile
Thigmotropism
Transduction
Transformation
Vertebrae
Virus
Xylem

UNIT 7: EVOLUTION & ECOLOGY

- 7.1 Ecology Basics
- 7.2 Evolution vs Equilibrium
- 7.3 Energy Flow
- 7.4 Succession and Biomes

Topic 7.1 Ecology Basics

Ecology is essentially the study of how organisms interact with each other, as well as how they adapt to the environment around them. Ecology expands beyond the molecular level of biology that we have talked about throughout the entire book.

How it Relates

The first few units in this book mostly covered everything that we could not visibly see due to their small size. We started with atoms, which made up molecules, which made up organelles, making up cells. Then, in the body system unit, we covered how cells make up tissues, how tissues made organs, and how organs made organ systems. Most recently, we talked about how organs made up different organisms. Now, we will go beyond that and expand into the larger world.

A single **organism** is one single living object that is able to reproduce with other organisms of the same species. A **species** is a group of organisms with enough similar genetic material that allows them to interbreed. Each organism has a **niche**, or role in its environment. When several species have a similar niche, competition occurs between them, and the species that are better suited for the environment will "win out", causing the "losing" species to either decrease in population or relocate.

A **population** is a group of the same organisms living in the same location. They will all be of the same species as well. An example of this would be a school of fish, all of the same species. Many populations in an area will create a **community**. For example, this could include a population of fish, as well as a population of another organism like a sea anemone. Communities only include the **biotic factors** in a location, which is anything that is living. Once we add the **abiotic factors** into the mix,

which are things such as water and air that are nonliving, we get an **ecosystem,** which is all the living and nonliving things that contribute towards a specific location. As a certain ecosystem increases the number of species living within it, it increases its own **biodiversity**.

Interactions

The term **symbiosis** refers to whenever two separate species have a certain relationship with each other, whether it harms or helps each party. There are three main types.

- **Mutualism** occurs when both organisms receive a benefit from their relationship. An example would be flowers depending on bees for pollination, while bees also receive a food source.
- **Commensalism** is when one organism benefits, while the other is unaffected. An example is a barnacle riding on a whale for transport. While the barnacle is able to be transported quickly, the whale does not benefit, nor is it harmed.
- **Parasitism** is when one organism is benefitted to the detriment of another. One example is a mosquito biting a human for blood.

There are other interactions between organisms that can happen. **Predation** is where one organism consumes another. **Competition** is when two organisms fight for survival, whether it be for food, land, or something else.

Topic 7.2 Evolution vs Equilibrium

The idea of evolution is that over a long period of time, populations will gradually change parts of their genetic information. When a population does not evolve, it maintains equilibrium. Evolution can only happen within a population of organisms and over a long duration.

Scientists

Coming up with the idea of evolution involved the work of many scientists, and while some were incorrect in their theories, they helped to pave the way to our current knowledge about how species change over time.

Carolus Linnaeus, who is also remembered for his contribution to the binomial naming system, is known as the "father of taxonomy" because he helped to efficiently categorize organisms based on shared traits.

Georges Cuvier studied fossils and believed in the idea of catastrophism, or the belief that organisms changed due to rapid environmental changes and extinctions of species.

James Hutton and **Charles Lyell** contrasted Cuvier because they believed in **gradualism** after studying the slow land changes in geological layers. They proposed that since natural processes take very long periods of time to have a significant impact, changes within organisms must have taken a long time as well.

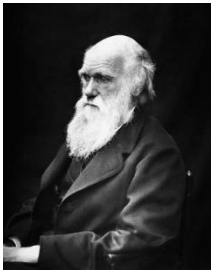
Jean-Baptiste Lamarck believed in two concepts: "use-and-disuse" was the idea that organisms who did not use a certain body part more would enhance that part, making it stronger or larger, and will pass it on to future generations; the other idea was "inheritance of

acquired traits", which was the belief that the adaptations that a parent organism received in its lifetime will pass down to their children. Both these theories were inevitably proven wrong since individual organisms cannot affect the genetic information of future populations.

Thomas Malthus believed that the growth of populations will eventually slow down when access to resources are not enough. This was crucial for the idea of natural selection.

Alfred Wegener made the "Continental Drift" Theory, which said that continents slowly moved apart over time. This is significant because it implied that populations would eventually become geographically isolated.

Stanley Miller and **Harold Urey** conducted experiments that discovered that certain organic compounds could be formed in a primitive environment. This proved that if certain molecules could be produced a long time ago, then organisms that relied on these molecules were able to live and undergo evolution.



Charles Darwin, perhaps the most important scientist for contributing to the study of evolution, wrote a book about natural selection after studying finches and tortoises on the Galapagos Islands.

Natural Selection

So, what is natural selection, anyways? Essentially, it is a process in which the organisms better adapted to their surroundings will be able to reproduce and affect the genetic makeup of the future population. An **adaptation** is a feature inherited from a parent that better allows an organism to survive within an environment. **Structural adaptations** are adaptations that are physically present on an organism that protects itself from harm or allows it to gain necessities like food. Examples include camouflage and sharp teeth. **Behavioral adaptations** are traits inherited by parents that change how an organism reacts to external events. Examples include migration and hibernation.

There are five main components to natural selection:

1. In every population, there is variation, meaning some organisms have a slightly different genetic makeup than others.

2. Most species will have an overproduction of offspring, meaning they will produce too many children to support.

3. The large amounts of offspring will compete for resources.

4. Those that have the greatest **fitness** will survive. Fitness is the ability for an organism to live long enough to reproduce.

5. The way fitness is determined is by nature and the obstacles that organisms must overcome to live as long as possible.

Natural Selection can occur in three different ways, and they rely on **selective pressures,** which are factors caused by the environment that may inhibit the success of an organism to reproduce. **Stabilizing selection** is when the average trait within a population is desirable and benefits an organism the most. For example, a human baby will best survive with an average weight; if it is too light or too heavy when born, it could hinder their ability to live as long as other humans. **Directional Selection** is when one extreme trait is desirable when adapting to the environment. For example, the longer the neck of a giraffe, the better it is able to get nutrients from leaves from tall trees, meaning the giraffes with longer necks will live longer and are more likely to reproduce, passing on their traits. Finally, **disruptive selection** is where instead of one extreme, both extremes are favorable for adapting to the environment. An example is hummingbird beaks, where those with small and long beaks can have access to different types of flowers.

Contrasting natural selection is **artificial selection,** which is where certain breeds are intentionally bred together to create an organism with the best traits possible. Artificial selection is usually done by humans,

like when farmers breed certain crops in order to get the most efficient one in terms of growing and harvesting.

Mechanisms for Evolution

Natural Selection is just one way that populations can evolve over time. Those that are better able to survive will reproduce, making offspring with the same adaptations. Eventually, the population of a specific species will have more organisms with favorable traits, and the population will evolve. Here are the other four ways that a population can change over time.

Mutations are random events that cause a change in the genetic code of an organism. This cannot be controlled by the parents, and although some can be harmful to the offspring, others can actually enhance it to live longer to pass their traits on.

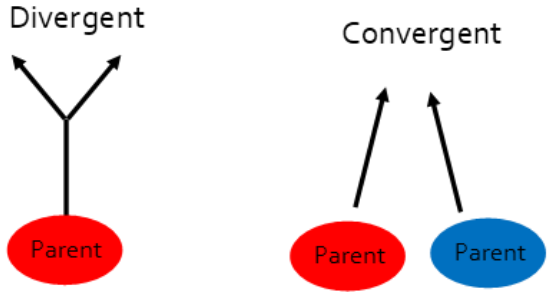
Gene Flow is also known as migration. As organisms of the same species move into a location, which is called immigration, it will increase the variation of a population. As species leave a location, a process called emigration, it decreases the amount of variability. As both types of migration occur, genes are transferred between the two previously separate populations.

Genetic Drift is where a population rapidly and randomly changes due to a sudden change in population size. The **founder effect,** for example, is when a few individuals from a specific species create

their own separate "community". Another example is the "**Bottleneck Effect**", where a natural disaster may kill off the majority of a population, leaving only a few individuals alive. When either of these events occurs, the **gene pool** of the smaller population may not be representative of the prior whole population, which will cause a change in what traits are passed down. A gene pool is simply all the genetic information within a population that is available to be given to an offspring.

Non-random mating means that males and females will choose each other for a specific reason while rejecting others. Reasons for this include specific traits that make a mate look more attractive, geographic limitations, and how similar potential mates are to each other. When non-random mating occurs, the variation in a population will decrease since only certain individuals will receive mates.

Patterns of Evolution



Now that we know how a population can undergo evolution, let's discuss the different ways it can occur. **Divergent Evolution** is when a single species will give rise to two different species as they eventually adapt to different environments and conditions. **Convergent Evolution** is the opposite of this, where two distinct populations undergo evolution to the point that they have similar traits. **Coevolution** is where the evolution of one species causes the evolution of another species. This is prominent in predator-prey relationships. **Punctuated Equilibrium** is the theory that changes in a population will happen in brief time periods and will then follow with a long period of time of no evolution. This is contrasted by **gradualism**, where species will gradually change over time through adaptations.

Evolution can cause changes in specific body structures over time. For example, convergent evolution can lead to **Analogous Structures**, where the purpose of a body part is the same between two different species, but their structure is different. An example of species with analogous structures is butterflies and birds, which both use wings to fly despite not having a common ancestor. **Homologous structures**, on the other hand, are caused by divergent evolution, where the structure of a body part is the same, but its function differs. This is notable in the bone composition in a human arm versus a whale flipper. While they have similar bones in that section, they serve drastically different purposes as the two species adapted to their respective environments. Finally, **Vestigial Structures** are body parts that disappeared over time since it no longer serves a function

in an organism. An example would be a tail, which is present in animals related to humans but is absent in humans since we do not need them to survive.

Speciation

A species is a group of individuals that are able to interbreed with each other. If two organisms cannot successfully create offspring, they are considered two different species. There are exceptions to this with things such as **hybridization**, where organisms of two different species can form a new organism; for example, a mule is the offspring of a horse and a donkey.

Species can be helped defined by **prezygotic barriers**, which are obstacles preventing two organisms from attempting to mate. Some examples are habitat isolation, where species living far apart are unlikely to find each other to mate, as well as behavioral isolation, where some animals have mating rituals that are not applicable to another species. Temporal isolation is

where two populations mate at different times, so they will never interbreed. Mechanical isolation is where the anatomical structure of two organisms prevents them from creating offspring. Finally, gametic isolation is where gametes unsuccessfully form a zygote.

Species are also defined through **postzygotic behaviors,** which prevent a newly formed organism from surviving or creating new organisms of that species. If the embryo stops development due to genetic incompatibility, it is known as reduced genetic viability. If an offspring is formed but is sterile and unable to reproduce, it is called reduced hybrid fertility. Finally, if the new offspring is fertile and can reproduce, but its offspring are weak, it is called hybrid breakdown.

Evidence for Evolution

There are many ways that scientists have concluded that evolution is occurring. Here are a few of these examples.

Scientists have observed that the embryonic stages of different organisms are similar, called comparative embryology. For example, all vertebrae have a transition during their early development where they all have gills and tails, regardless of whether they will appear in the final fetus.

Comparative anatomy, on the other hand, looks at the actual structures of living organisms and compares them with each other. This goes back to what we

previously talked about with analogous, homologous, and vestigial structures.

In addition, Fossil records have shown that environmental changes over a long period of time can lead to gradual changes in the skeletal structure of organisms.

Molecular Biology is the process in which we look at DNA and genetic material to look for similarities and differences. We have found that more similar species share more genetic material in common compared to species that are more different as a result of earlier evolution.

Biogeography is attributing the differences in species based on where they live. Two primary examples of this are convergent and divergent evolutions.

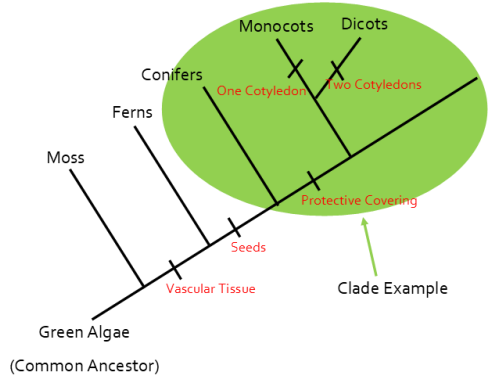
Finally, **endosymbiosis** is the theory that mitochondria and chloroplast were previously their own prokaryotic cells a long time ago, eventually entering inside another cell, causing that cell to evolve over time. Scientists believe this to be a valid hypothesis because both mitochondria and chloroplast have a double membrane similar to a prokaryotic cell, they can replicate through binary fission, and they contain their own circular DNA and ribosomes.

Cladograms and Phylogenetic Trees

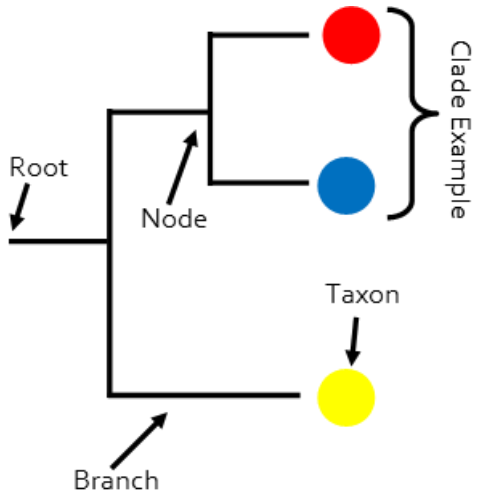
Both of these are diagrams that scientists use to show the evolution of a group of species over time. The study of these relations is called **phylogeny**, and a **cladogram** is a diagram that is able to analyze features that were obtained over a long period of time. There are

a few key features of a cladogram that we must be familiar with.

- The first organism, usually depicted at the bottom of a cladogram, is the "original" organism that gave rise to the new organisms later on in its evolutionary history
- As new organisms arise as you go up the cladogram, each one will have a unique trait that the ones below it does not have. All the organisms above any single organism will share all the same traits and may possibly have new traits.
- When a cladogram divides into separate branches, it means that they share the same traits as all the organisms below it but can be differentiated based on another unique characteristic.
- Organisms closer together on a cladogram are more similar to each other than ones that are farther apart.
- Any group consisting of organisms that share a common ancestor is called a **clade.**



Phylogenetic Trees are another way of depicting shared derived characteristics. Rather than being a mostly linear path with some branches out, a phylogenetic tree contains **nodes** where two organisms split due to varying traits. On a phylogenetic tree, the single organism on the left is at the **root,** and all the **branches** coming off of it eventually reach a **taxon** or one specific species. On both cladograms and phylogenetic trees, whenever there is a split, it results in **speciation,** the creation of a new species.



Hardy Weinberg Equilibrium

When a species does not undergo evolution and the gene pool remains the same, it is known as **equilibrium.** The five mechanisms required for equilibrium are the opposite of the five required for evolution.

1. Instead of natural selection, no natural selection occurs.
2. There is a large population size, so no genetic drift occurs.
3. There are no mutations.
4. Mates will randomly pair with each other rather than being selective.
5. There is no gene flow, and migration does not occur within these populations.

When equilibrium occurs, we can use equations to calculate the frequency of alleles within a population. Here are the two equations

$$p+q=1$$
$$p^2+2pq+q^2=1$$

where p is the frequency of the dominant letter for all the organisms within a population, q is the frequency of the recessive letter, p^2 is the frequency of homozygous dominant individuals, 2pq is the frequency of heterozygous individuals, and q^2 is the frequency of homozygous recessive individuals. Let's look at an example.

Let's say you know that 75% of flowers are red and 25% are white, with red being dominant over white. Using R for red and r for white, we know that the frequency of rr is .25, so $q^2=.25$. We can take the square root of that value to find q, which is .5. Now we can use the first equation to find the value of p, which is also .5. We can use that value to find p^2, which is .25. Finally, in

order to find the frequency of heterozygous individuals, we can plug it back into the second equation and find that 2pq is .5.

Quick Tip:

Note that you can't use .75 in order to solve for the frequency of R alleles. This is because you only know the phenotype of the plants, so .75 is the value of both homozygous dominant and heterozygous flowers. ($p^2+2pq=.75$)

RR

rr

Rr

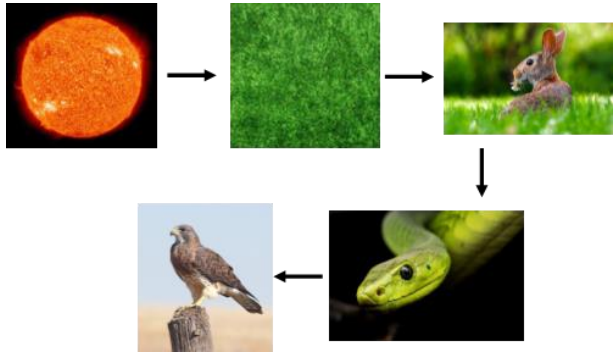
Rr

Topic 7.3 Flow of Energy

In order for any organism to survive on its own, it must be able to obtain energy, whether it be from the sun or from another organism. When a group of organisms in an ecosystem rely on each other for nutrients, we can create diagrams displaying their relationships.

Food chains and Food Webs

The transfer of energy from one organism to another follows a single path, and it always begins with the sun, which supplies energy to **producers**. Producers are the first organisms to be found in a food chain or web because they utilize light energy and convert it into chemical energy, which they can then use as food. All other organisms that rely on another organism, whether it be a producer or another non-producer, are called **consumers**. Depending on what they consume, they are referred to as different names. **Herbivores** will only consume producers, while **Carnivores** will only eat meat. **Omnivores**, on the other hand, will eat both plants and animals. **Detrivores** rely on dead organisms for energy. Two examples of detrivores are **decomposers** and **scavengers.** Decomposers like fungi will break down dead organisms, causing decay. Scavengers will actually consume the dead matter, such as vultures.



A **food chain** will only depict one possible pathway of the transfer of energy. Whenever you see the arrows, they will always point towards the organism that is

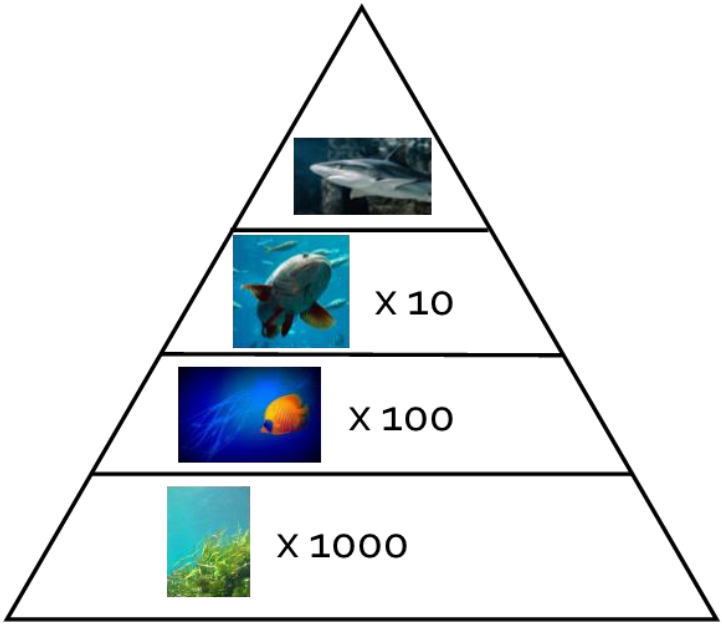
receiving the energy. A **food web**, on the other hand, is a collection of multiple interconnected food chains that can show the transfer of energy. Each organism can be categorized into different trophic levels, which is the order in which energy is transferred.

- The first trophic level is always the autotroph or producer, relying on the sun for energy
- The second trophic level is an herbivore that consumes the producer and is also referred to as a **primary consumer.**
- The third trophic level consumes the herbivore and may also consume producers. They are called **secondary consumers.**
- The fourth and fifth trophic levels are usually carnivores and are called tertiary and quaternary consumers, respectively. Whichever organism is at the top of the food chain or web, meaning no other organisms consume them, they are called a "top carnivore". One prominent example of this is humans.

Energy Transfer

When energy is transferred from, say, a producer to a primary consumer, not all of that energy is transferred completely, even though the entire organism is consumed. Most of the energy is lost as heat; specifically, only 10% of the energy from the producer is used up by the primary consumer for chemical energy, while the remaining 90% is released into the earth. This is known as the **10% rule**. This

information can be displayed on an **energy pyramid**, which will show the energy available at each trophic level. As you move up the pyramid, less biomass of each species will be present because there is not enough energy in higher trophic levels to support high populations.

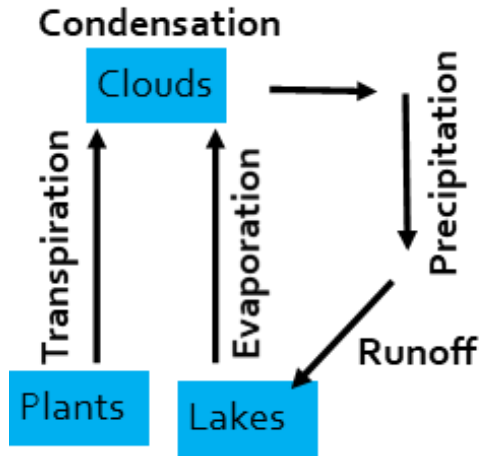


Biological Magnification is where toxic materials end up being concentrated in higher trophic levels. This is because as organisms in lower trophic levels are exposed to things, such as pollutants, the organisms that consume them will receive the same pollutants, and then their consumers will receive it as well until it reaches the top carnivore or the higher trophic levels.

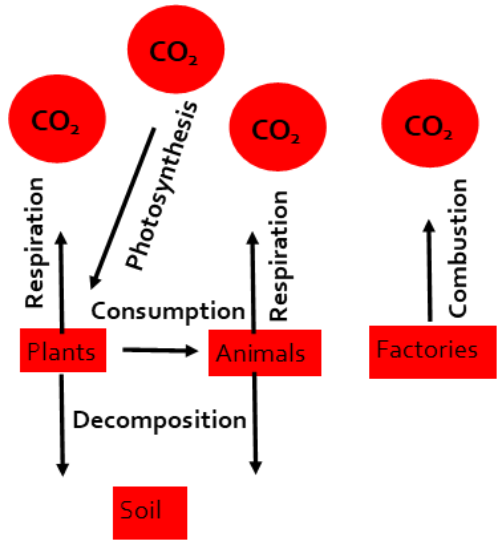
Cycles

Energy is not the only thing that moves around the earth. Atoms and molecules can as well. There are several cycles that are important for the Earth to function the way it does; some include the water cycle, the carbon cycle, and the nitrogen cycle. Let's start with the one you are likely most familiar with.

The **water cycle** involves water in the different states of matter as it moves around the earth. Liquid water is turned into gas with the process of **evaporation** and **transpiration.** Transpiration is the release of water from plants as a byproduct of photosynthesis. As this vapor undergoes **condensation** and becomes solid, it will eventually fall and become **precipitation**.



The **carbon cycle** involves the recycling of dead organisms that contain carbon and releasing it into the air as carbon dioxide. Carbon can also be created by plants, which can be consumed by animals.

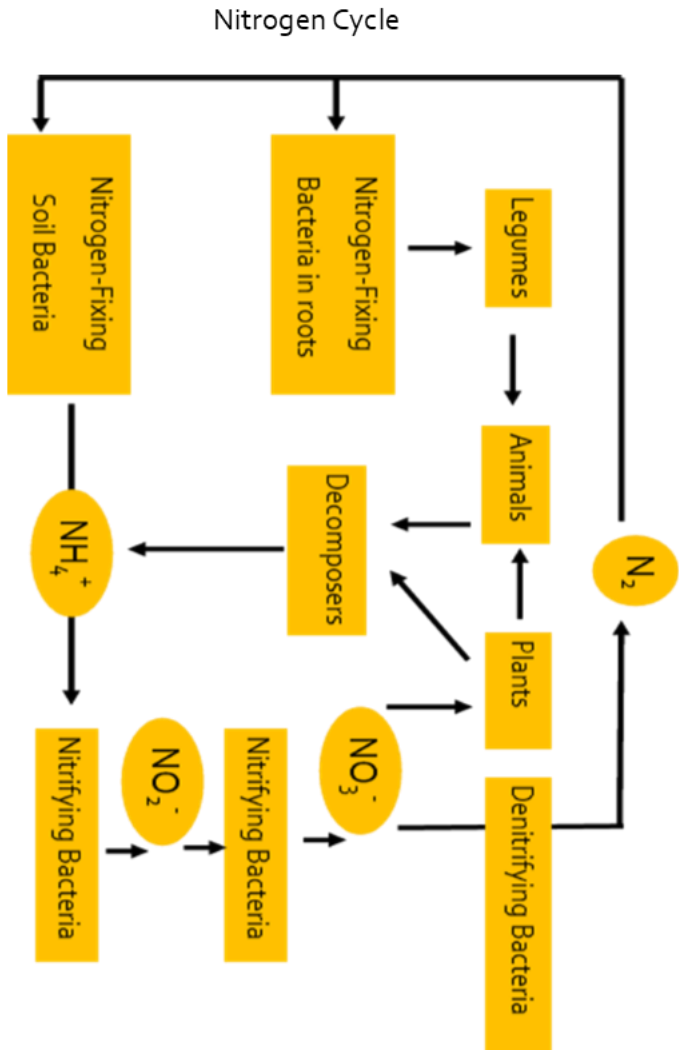


The **nitrogen cycle** is probably the most complex out of the three. This is because nitrogen can be a part of different molecules, with some being more usable than others. Here is a basic outline of what happens:

- After organisms perish, nitrogen is supplied into the soil as they decompose.
- Since plants cannot directly use this form of nitrogen for nutrients, the nitrogen needs to be converted into usable forms. Some plants called **legumes** have nitrogen-fixing bacteria attached to them that can convert the nitrogen into a usable form. Other plants simply rely on other bacteria like **nitrifying bacteria** to convert the relatively unusable ammonium (NH_4^+) to more usable forms for plants like Nitrate (NO_3^-).
- Other bacteria will take the nitrogen that was usable by plants and convert it back into

atmospheric nitrogen (N_2). These are called **denitrifying bacteria**.

- Animals can also eat the plants and use the nitrogen present in them for nutrients. Remember that nitrogen is highly present in amino acids and proteins, so every organism contains some nitrogen within them.



Topic 7.4 Succession and Biomes

There is a large diversity of biomes on earth, and they can either be on land or in the water. **Biomes** consist of numerous ecosystems spanning a large area, and all the biomes on earth make up the **biosphere.** Changes in communities can lead to succession.

Succession

The term succession refers to the gradual change of an area over time. There are two different types of succession; primary and secondary.

Primary Succession occurs whenever there is no soil present at the beginning. The first living organisms that colonize this land, which are called **pioneer species**, must convert the bare ground into usable soil for other organisms. Pioneer species include things like lichen. Once the bare rock becomes soil, other organisms like moss can begin to colonize the land. After that, more advanced organisms like grasses can live there. Next, plants such as pine trees will start growing there as the environment becomes more suitable for it. Finally, the most complex organisms like deciduous trees (the ones that change color leaves with the changing seasons) can move in. This final stage of ecological succession is known as the **climax community**, and it will continue until a natural disaster causes the living organisms to die out and cause succession to repeat once again. **Secondary succession** is the same process as primary succession, but it has soil in the beginning. Therefore, it takes much less time for secondary succession to reach a climax community. Natural disasters that can cause primary succession to restart are things that deplete the

earth of soil, including volcanic eruptions. Natural disasters that will not get rid of the soil and will cause secondary succession include hurricanes and forest fires.

Terrestrial Biomes

There are several biomes around the earth that are found on the land. Here is a list of some of them.

The **tundra** is found at the poles of the earth, and have permafrost, meaning the soil is frozen year-round. Because of this, few plants are able to live here. The animals that live here must have adaptations that allow them to do so, like caribou.

The **taiga** consists of coniferous trees and is located in higher latitudes not as extreme as the tundra. The taiga has long winters, and animals that live here

adapt through hibernation (such as grizzly bears) and migration.

Deciduous Forests have more precipitation, and there are distinct seasons in these areas. They are also called temperate forests because of their less extreme climate conditions. Some animals that live here are deer and foxes.

The **savanna** is also referred to as the grasslands because of the presence of lower growing plants and few trees. This is because there is usually not as much rain, and animal grazing is common. Animals that live here include antelope and bison.

Tropical rainforests have the most precipitation and have the greatest diversity of plants and animals.

Tall trees tend to create a canopy, which makes it hard for sunlight to reach the surface of the earth.

Deserts are the opposite of tropical rainforests, with little to no precipitation annually. Plants need to be able to store water for long periods of time in order to live here, such as cacti, while animals must learn to adapt to the dry, hot weather by being nocturnal, only coming out at night. There are cold deserts as well, such as in Antarctica.

Aquatic Biomes

Biomes that are found in the water tend to be more stable. They are separated into freshwater biomes and marine biomes (saltwater biomes).

Freshwater is split into three different biomes. The **Littoral Zone** is the section close to the shore. The **Limnetic Zone** includes the areas that light can travel through. Here, plants are able to thrive off sunlight and photosynthesize. The **Profundal Zone** is the area below the Limnetic Zone, and little light is

available here. Therefore, more secondary consumers tend to live here.

The Marine biome is also split into three zones. The **Intertidal Zone** is close to the shore and is named for the fact that when there is a low tide, sometimes organisms like sea stars are exposed to the atmosphere. The **Neritic Zone** extends a little more beyond the Intertidal Zones, where there is warm water and shallow depths. Plants like seaweed live here. Finally, the **Oceanic Zone** is basically open water and is split between the **Pelagic** and **Benthic Zones** which are the upper and lower layers of the Oceanic Zone, respectively.

Unit 7 Vocabulary Terms

10% Rule
Abiotic Factors
Adaptation
Analogous Structure
Artificial Selection
Behavioral Adaptation
Benthic Zone
Biodiversity
Biological Magnification
Biome
Biosphere
Biotic Factors
Bottleneck Effect
Branch
Carbon Cycle
Carnivore
Clade
Cladogram
Climax Community
Coevolution
Commensalism
Community
Competition
Condensation
Consumer
Convergent Evolution
Cuvier, Georges
Darwin, Charles
Deciduous Forest
Decomposer
Denitrifying Bacteria
Desert
Detrivore
Directional Selection
Disruptive Selection
Divergent Evolution
Ecosystem
Endosymbiosis
Energy Pyramid
Equilibrium
Evaporation
Food Chain
Food Web
Founder Effect
Gene Flow
Gene Pool
Genetic Drift
Gradualism
Gradualism
Herbivore
Homologous Structure
Hutton, James
Hybridization
Intertidal Zone
Lamarck, Jean-Baptiste
Legume

Limnetic Zone
Linnaeus, Carolus
Littoral Zone
Lyell, Charles
Malthus, Thomas
Miller, Stanley
Mutation
Mutualism
Natural Selection
Neritic Zone
Niche
Nitrifying Bacteria
Nitrogen Cycle
Node
Oceanic Zone
Omnivore
Organism
Parasitism
Pelagic Zone
Phylogenetic Tree
Phylogeny
Pioneer Species
Population
Postzygotic Barrier
Precipitation
Predation
Prezygotic Barrier
Primary Consumer
Primary Succession
Producer
Profundal Zone
Punctuated Equilibrium
Root
Savanna
Scavenger
Secondary Consumer
Secondary Succession
Selective Pressure
Speciation
Speciation
Species
Stabilizing Selection
Structural Adaptation
Succession
Symbiosis
Taiga
Taxon
Transpiration
Tropical Rainforest
Tundra
Urey, Harold
Vestigial Structure
Water Cycle
Wegener, Alfred

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Wiley Liou, born in Dallas, Texas, is a currently a 17-year-old 11th grade student at Lebanon Trail High School in Frisco, Texas. Hoping to share his knowledge he gained in his high school biology classes, he wrote *Fundamentals of Biology* to serve as a study guide for fellow students or for anyone hoping to learn more on the expansive field of science.