Biology Notes v. 0.2

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Preface and Disclaimer

This is a series of notes for AP Biology. These notes are NOT comprehensive, and may not have topics in the order in which we cover them in class or the order in which they appear in your textbook. Furthermore, there will be topics covered in these notes that you will not be tested on, and there will be topics you will be tested on that are not covered in these notes. In addition, I provide no guarantee that the level of detail or accuracy of these notes will be sufficient to prepare you for any assessments you may be using them to prepare yourself for. Therefore, you will also need to study other assigned material spoken about or handed out in class, posted on OneNote, as well as the textbook, in order to prepare yourself for any assessments.

Please let me know if you find any typos, errors, or confusing statements, as I will be updating this document regularly.

Your textbook will be referred to as POL throughout these notes (Hillis, 2014).

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1. Basic Chemistry

1.1. The Atom

An atom is the smallest unit that retains the properties of any one particular element. Atoms can contain 3 types of subatomic particles; the electron, the proton, and the neutron. The proton and neutron are found together in the central region of the atom, referred to as the **nucleus**. The electrons are found in orbitals in the periphery of the atom.

These different subatomic particles also differ in other properties. Compared to the proton and neutron, the mass of the electron is essentially negligible. The proton and the neutron have very similar masses, both approximately 1800 times greater than that of the electron. Since the masses of all of these particles are very small when viewed in standard units such as grams, we use a different unit when measuring the masses of atoms and their subatomic particles, the atomic mass unit or amu. In these units, for the sake of our course, we will say that the proton and neutron each have a mass of 1 amu while the electron has a mass of 0 amu. We also may consider the charge of each of these particles. The electron has a negative charge, the neutron is uncharged, and the proton has a positive charge equal in magnitude to that of the electron.

The particular element an atom is determined by the number of protons in the atom, this number is referred to as the **atomic number** and is unique to each element. On the other hand, the number of electrons or neutrons need not remain constant for an element to retain its identity. If we compare a sodium atom with 11 electrons to one with 10, we notice one important difference. The second sodium atom, with its 10 electrons does not have a neutral charge, as sodium has 11 positively charged protons, but this particular sodium atom only has 10 negatively charged electrons. We say that atom is an **ion** as it has a nonzero charge, and in this particular case, we see an ion with a charge of +1, as it has one more proton than it does electrons.

We can also identify the mass number of a particular atom, which is the sum of the number of protons and neutrons in the atom. Different atoms of the same element may have different mass numbers, and therefore different numbers of neutrons. These different forms of the same element which differ only in the number of neutrons are called isotopes.

Another property is the **standard atomic weight** of an element. This quantity is the weighted average of the atomic masses of the different isotopes according to their natural abundance.

$$W_a = \sum_i (A_i f_i)$$

In the above formula, W_a is the atomic weight of the element, A_i is the mass of the i^{th} isotope, and f_i is the relative frequency of the *isupth* isotope. Obviously, for the above formula to make sense, the sum of all the frequencies should equal 1.

1.2. Bonds

There are two types of chemical bonds of interest to our study of biology, the covalent bond and the ionic bond.

1.2.1.

Covalent bonds are formed when two atoms share electrons. In this case, we have two atoms close together such that we can consider one electron from each of them to be shared and count towards the valence shell of both of the atoms. Thus, a single covalent bond consists of two valence electrons, shared between two atoms. The sharing of the electrons may be equal or unequal. We have a scale to measure how well a particular element is able to attract electrons called **electronegativity**. The general trend on the periodic table is that electronegativity increases as you move up and two the right on the table, excluding group 18. Therefore fluorine has the highest electronegativity of any element. With covalent bonding, the two atoms have similar electronegativities. If the difference is less than .9 (electronegativity is a unit-less quantity) we consider the electrons to be shared equally and the covalent bond to be a **nonpolar covalent bond**. If the difference is greater, the bond is a **polar covalent bond**.

In the situation where we have a polar covalent bond, the atom with the higher electronegativity has a partial negative charge, due to having the negatively charged electrons spending more time around it, and the one with the lower electronegativity is considered to have a partial positive charge.

1.2.2. Ionic Bonds

Ionic bonds occur when there is an extremely large difference in the electronegativity between two atoms. Generally, we see that one atom is quite close to having a full valence shell, however it needs to lose one or more electrons, while there is another atom which is also quite close to having a full valence shell, however it needs to gain one or more electrons.

Let's look at Sodium and Chlorine. They are both highly unstable in their uncharged monoatomic forms. Sodium has one electron in its valence shell. Chlorine has seven. Owing to the octet rule, which is the heuristic that atoms are generally stable with eight valence electrons in their shell, we see that chlorine will be highly electronegative, as if can gain one electron, it will be stable and have eight electrons in its shell. On the other hand sodium has only one valence electron, and therefore does not want to gain an electron, it wants to instead lose its one valence electron, have the shell one lower become its valence shell which is already full with eight electrons. An ionic bond can form between these two atoms, whereby one electron is transferred from sodium to the chlorine[1]. In this process the transfer of the electron makes the two atoms become ions. The sodium, having lost an electron, now has a +1 charge state, while the chlorine now has a -1 charge state.

Ionic bonds can also be formed between more than two atoms. For example, magnesium chloride (*MgCl_2*) is formed by magnesium losing two electrons, with one going to one chlorine atom, and the other going to a second chlorine atom, again, filling the valence shells of all involved atoms, greatly increasing their stability.

1.3. Water

Water is a molecule which is critical to life. It has certain chemical properties underlying this importance[2].

1.3.1. Hydrogen Bonding

Water is very capable of participating in hydrogen bonding. **Hydrogen bonds** are inter-molecular forces, not true examples of chemical bonds. They occur between fluorine, nitrogen, or oxygen, and a polar hydrogen. A polar hydrogen is one which has a partial positive charge due to being covalently bound to a polar atom.

[1] See POL p. 25, figure 2.6 for a diagram of this process.

[2] Please refer to POL pp. 22-24 for figures relating to this section.

A water molecule can hydrogen bond with both other water molecules, and other polar molecules which contain F,O,N or polar hydrogen.

This provides something very close in strength to an actual bond, as it is much stronger than all of the other types of inter-molecular forces. We will see that water's ability to participate in hydrogen bonding with other molecules leads to many of its important properties for life.

1.3.2. The Universal Solvent

Owing to its polarity and the process of hydrogen bonding, water is capable of dissolving a great many polar substances. Remember "like dissolves like" and therefore water is ineffective in dissolving non-polar substances like lipids. However many of the macromolecules of life, including nucleic acids, carbohydrates, and most proteins are polar and will dissolve in water.

1.3.3. Heat capacity

Water has a very high heat capacity. The heat capacity of a substance is a quantity specifying how much energy it takes to raise the temperature of the substance. Since organisms are generally mostly made of water, this means that body temperatures will not rise and fall as quickly as air temperatures. This also means that processes like sweating are effective in lowering body temperature, as a great deal of heat is lost from the body in the process of evaporation of sweat.

1.3.4. "Stickiness"

Water is very good at sticking to other molecules, which is related to hydrogen bonding. Adhesion and cohesion are related processes, with adhesion meaning two different types of things sticking together, and cohesion meaning that two of the same type of thing stick together. We see water undergoing both processes. We also see both of these processes in capillary action, the process by which water is able to climb up materials such as plant stalks.

Surface tension is the other important cohesive phenomena. Here we see water molecules at the surface of a substance sticking together via hydrogen bonding. It takes a certain amount of pressure for items to break through the surface of water due to its high surface tension.

1.3.5. Ice Floats!

The solid form of water is less dense than its liquid state. Due to this fact, ice floats, which is crucial to life on Earth. If this were not true, the oceans would be frozen solid and only a few inches at the top would melt during the warmer months. Water is less dense as a solid due to the fact that the hydrogen bonds leave ice in a very ordered regular structure, while the hydrogen bonding in water is more random, and the molecules are generally closer together in liquid water, leading it to be more dense than ice.

1.4. Polymers

In the next chapter, we will look at the four classes of biological macromolecules. Three of the four classes consist of **polymers**. Polymers are long chemicals which consist of repeating sub-units called **monomers**.

2. The Biological Macromolecules

There are four different classes of biological macromolecules. We will cover each of them in this chapter. Each of them play important and distinct roles in organisms.

2.1. Carbohydrates

2.1.1. Introduction

Carbohydrates are utilized in diverse roles throughout organisms. They are primarily used for energy, structure, and signaling. Carbohydrates are found in both monomer and polymer forms.

Many, but not all carbohydrates are named with -ose as their suffix, so seeing that at the end of a word should give you a hint that a carbohydrate is being spoken about.

The general chemical structure of carbohydrates is carbon chains with attached alcohol (-OH) and carbonyl (C=O) functional groups. This leads to carbohydrates generally being quite soluble in water due to their polarity.

2.1.2. Monosaccharides

Monosaccharides are the monomer units that are used to form all complex carbohydrates. The most common example of a monosaccharide is glucose, which is a substance used for energy throughout life.

To classify monosaccharides like glucose, we count the number of carbons on the molecule. Glucose, for example, is a hexose, with the prefix hex- telling us that glucose has six carbons. The other most common class of monosaccharides are

the pentose sugars, those with five carbons. Within this category we see ribose and deoxyribose, parts of the backbones of RNA and DNA respectively.

2.1.3. Disaccharides

Monosaccharides may be combined to form disaccharides. Examples of disaccharides include maltose, which consists of two glucose bound together, and lactose, which consists of a glucose and a galactose bound together.

The name of the bond holding the two monosaccharides together is the **glycosidic bond**. This bond is formed via a dehydration synthesis reaction, much like many other reactions we see for other types of biological macromolecules.

2.2. Lipids

The next category of the biological macromolecules are the lipids. Lipids are generally used for long term storage of energy and thermal insulation among other roles in organisms. Common substances which fall into the category of lipids include fats, oils, waxes and steroids. It is worth noting that this is the only one of our four categories of biological macromolecules that do not form polymers.

2.2.1. Fatty Acids

The most basic chemical component which is present in the majority of lipids is the fatty acid. The **fatty acids**
are organic molecules which consist of a carboxyl functional group attached to a long hydrocarbon chain, often referred to as a tail. These fatty acids are non-polar, owing to their long hydrocarbon tail.

Fatty acids can be either saturated or unsaturated. Saturated fats have the maximum number of hydrogen possible in their tail due to the absence of any carbon to carbon double bonds. The tails of these molecules are very straight, which allows these saturated fatty acids to pack tightly and increase the amount of inter-molecular forces between them. Due to this, saturated fatty acids are generally solid at room temperature. These fatty acids are found in high abundance in lipids derived from animals.

Unsaturated fatty acids have at least one carbon to carbon double bond in their tail, decreasing the number of hydrogen from the maximum, which makes them unsaturated. Natural unsaturated fats have their double bonds in the *cis*
configuration, leading to bends in the tails. This bending decreases how compactly these molecules fit together, therefore decreasing intermolecular interactions, leading to a lower melting points, such that they are generally liquid at room temperature.

There is one other type of unsaturated fatty acid, the *trans* unsaturated fatty acid. These are by-products of hydrogenation reactions used to convert *cis*
unsaturated fatty acids to saturated fatty acids. Notably, these trans fatty acids have an overall shape more similar to saturated fats compared to unsaturated fats. These molecules have been shown to have significant negative impacts on human health[3], and in the present day, are banned in many countries.

2.2.2. Triglycerides}

The triglyceride consists of one glycerol molecule bound to three fatty acids. The three fatty acids may be the same or different. These fats are a very common form of stored fat in organisms.

2.2.3. Phospholipids

Phospholipids are similar to triglycerides in that the molecule has a glycerol with its three attachment points. However, instead of three fatty acids being attached to the glycerol, there are only two, and the third position is taken up by what is called a phosphate head.

Notably, this phosphate head is charged and very polar. This means that unlike most other fats, phospholipids are not just non-polar, they instead have two regions, a non-polar tail and a polar head. This leads to the interesting characteristic of this molecule where the head part (polar) is hydrophilic and the tail is hydrophobic. A molecule having both of these types of sections is referred to as **amphipathic**.

2.3. Nucleic Acids

Nucleic acids are the macromolecules which are responsible for carrying information. While DNA has the role of holding the genetic information for the organism, RNA plays a wide variety of roles within the cell.

Nucleic acids are polymers, formed of nucleotide monomers. The two types of nucleic

[3] Read this page by the American Heart Association if you are interested in the health information about trans fats: [https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/fats/trans-fat]},

acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

2.3.1. Nucleotides

The nucleotide is the monomer of all nucleic acids. It consists of three parts:

- Pentose Sugar
- Phosphate
- Nitrogenous Base

The **sugar** contained within a nucleotide is either ribose (found in RNA nucleotides), or deoxyribose (found in DNA nucleotides). Both ribose and deoxyribose are pentose (5 carbon) sugars, differing in deoxyribose having an -H versus ribose having an -OH attached to the 2â carbon of the sugar.

Note that the carbons on the sugars are numbered clockwise around from 1’ (pronounced "One Prime") to 5’ ("Five Prime"). Connected to this sugar on the 5’ carbon is a phosphate, a poly-atomic ion consisting of a phosphorous connected to four oxygen atoms (*PO*_4). Phosphate is a poly-atomic ion with a -2 charge. Also connected to the sugar, on the 1’ carbon is a nitrogenous base. The nitrogenous base is what gives nucleotides and nucleic acids the capability to contain information.

In DNA there are four different nitrogenous bases that can be present: Adenine, Guanine, Cytosine, and Thymine. In RNA there is one difference in that Thymine is replaced by Uracil. The nitrogenous bases are divided into two categories, the purines - those with two rings (Adenine and Guanine) and pyrimidines - those with one ring (Thymine, Cytosine, and Uracil).

To grow a polymer consisting of nucleotides, the phosphate of one nucleotide is connected to the 3’ carbon of the previous nucleotide to form a phosphodiester bond between two nucleotides. Note that this occurs via a condensation reaction, the same type of reaction we see linking many other types of biologically relevant molecules together.

Now after the addition of the nucleotide, we still have a 3’ carbon which is open to the addition of another nucleotide. Nucleotides are always added to the 3’ end, not the 5’ end. At the other end of the polymer we see a nucleotide with a free phosphate group coming off of the 5’ carbon, which we call the 5’ end. A polynucleotide therefore has direction, starting at the 5’ end and ending at the 3’ end.

2.3.2. DNA

DNA is responsible for holding the genetic information of an organism, and passing it on to the next generation during reproduction. It accomplishes this by making a copy of itself prior to mitosis, and during mitosis, one copy is given to each of the two daughter cells formed.

The overall structure of DNA is a double helix, consisting of two polypeptides running anti-parallel to one another. By anti-parallel, we mean that the 5’ end of one strand is next to the 3’ end of the other strand and vice versa. We see that the backbone of either strand of the DNA are the phosphate and sugar groups while the rungs that extend across the central portion of the molecule are the nitrogenous bases. The nitrogenous base coming from one side of the double helix will always be met with a particular, complementary nitrogenous base on the other strand. For DNA, we will always see adenine pairing with thymine and guanine pairing with cytosine. The two nitrogenous bases are held together across the center of the double helix via hydrogen bonding.

2.3.2.1. DNA Replication

DNA replication is referred to as semi-conservative, this means that when one double stranded DNA molecule replicates into two double stranded DNA molecules, one of the strands of each of the daughter molecules will be from the original while the other will be newly synthesized.

2.3.3. RNA

RNA plays a diverse variety of roles within organisms. RNA consists of nucleotides containing the sugar ribose, and the base uracil is used in place of thymine.

Unlike DNA, RNA molecules are generally single stranded rather than double stranded. The single stranded RNA molecules fold into complex 3D structures.

2.3.4. Differences between DNA and RNA

The table below shows a summary of the differences between DNA and RNA.

DNA vs. RNA		
	DNA	RNA
Bases	ACTG	ACUG
Struct.	Dbl. Stranded	Sngl. Stranded
Sugar	Deoxyribose	Ribose
Function	Genetic Code	Various

2.4. Proteins

Proteins play a variety of roles in biological systems, functioning in diverse roles such as cell signaling, structure, transport, catalysis (enzymes), among many others. Proteins are examples of polymers. They contain repeating monomer subunits called amino acids.

2.4.1. Amino Acids

Within the Amino Acid, there are 4 components attached to the central carbon (also known as the alpha carbon), identified clockwise, starting at the top:

- **R Group** - At the top of the amino acid we the letter R. This is a placeholder for any functional group or combination of functional groups that are present in this location. This gives the amino acid a particular identity, as the rest of the amino acid will be the same for all amino acids. For example, if R is equal to CH3, we have the amino acid alanine, but if R is just a single hydrogen, we have the amino acid glycine.
- **Carboxyl Group** - This is located on the right side of the molecule (COOH). This is an acidic functional group present in all amino acids. This means that when we have the amino acid in an aqueous solution the hydrogen will leave and we will be left with COO(-), leaving the amino acid with a full negative charge on the oxygen previously covalently bound to the hydrogen.
- **Hydrogen** - We will always have a single hydrogen bound to the central carbon.
- **Amino Group** - This is located on the left side of the molecule (NH2). This is a basic functional group present in all amino acids. As this group is basic, we will see that the group will pick up a third hydrogen and a full positive charge (NH3+), when the amino acid is in aqueous solution.

2.4.2. Formation of Polypeptides - Under Construction

In order to form polypeptides, amino acids must be connected by dehydration synthesis (condensation). The name of the bond formed between the amino acids is the peptide bond. When we form polypeptides,we see that they have two distinct ends, one with the carboxyl group and one with the amino group, these are referred to the C-Terminus and the N-Terminus respectively. Polypeptides are considered to start at the N-terminus and end at the C-terminus, giving them a directionality akin to the 5â -> 3â direction of nucleic acids.

2.4.3. Levels of Protein Structure - Under Construction

When we look at the three dimensional structures of proteins we see that they are quite complicated. We therefore model the structure of proteins in four levels, starting with individual polypeptides.

2.4.3.1. Primary

The order of the amino acids present in a polypeptide from the N terminus to the C Terminus. Here, all we know is the identity of the amino acids within the polypeptides and their order. We know nothing yet about the three dimensional structure the polypeptide will assume.

2.4.3.2. Secondary

We now consider interactions among pieces of the backbone of the polypeptide, however we ignore the existence of the side chain (aka R group). From this we look at the peptide bond and see that the N-H and C=O can hydrogen bond with one another. Thus we can form two structures, the alpha helix and the beta sheet.

2.4.3.3. Tertiary Now we have to consider the behaviors of the different types of side chains present in amino acids.

- Non-polar - Non polar amino acids undergo hydrophobic interactions. These residues will bunch together toward the center of the 3D structure of the polypeptide in order to face away from the water that surrounds the polypeptide.
- Polar - These will perform hydrophilic interactions meaning that they will generally face towards the outside of the polypeptide in order to interact with water. They also may form hydrogen bonds with one another.

- Disulfide linkages - Cysteine is an amino acid which contains a sulfhydryl functional group in its side chain. Cysteine residues are able to connect to one another via disulfide bonds.
- Basic and Acidic - Basic and acidic residues will interact with each other and form salt bridges due to their abilities to form ionic bonds.

2.4.3.4. Quaternary

The quaternary level of protein structure is seen in proteins that consist of more than one polypeptide. Each of the three levels of structure below quaternary only consider one single polypeptide. However, many proteins are formed from multiple polypeptide chains coming together. In proteins like these, we see the same types of interactions that are witnessed at the tertiary level of structure, however they are now occurring between amino acid residues which are members of different polypeptide chains.

2.4.4. Enzymes

Enzymes are a very important type of protein to cells. They are responsible for catalysis of chemical reactions. Catalytic agents, or catalysts, including enzymes, are substances which increase the rate of chemical reactions without undergoing any changes themselves. Most chemical reactions that take place in the realm of life would not proceed forward quick enough if it were not for catalysts.

3. The Cell

The Cell is the fundamental level of biological organization. This is due to the fact that the cell is the lowest level of organization where we see all of the life processes occurring.

3.1. Cell Theory

Cell theory is a unifying theory of biology. It contains the following three postulates:

- The cell is the fundamental unit of life.
- All organisms are composed of cells.
- All cells come from preexisting cells.

While these may seem obvious to you, this theory was revolutionary in its time, and is fundamental to the way we study biology today.

3.2. Cell Volume

Cells are the small size they are due to the need for a high surface area to volume ratio. If we were to increase the size of a cell, the cell's volume would increase at a higher rate than its surface area.

If we model a cell as a sphere, its volume is

$$V = 4/3\pi r^3$$

$$S = 4\pi r^2$$

Let us see what happens if we take the ratio of the surface area to the volume of a sphere:

$$\frac{S}{V} = \frac{4\pi r^2}{4/3\pi r^3}$$

$$\frac{S}{V} = \frac{3}{r}$$

We see that the surface area to volume of a sphere is $\frac{3}{r}$. This shows that as we increase the radius of a sphere, its surface area to volume ratio will decrease.

Why is this a problem?

This is an issue due to the fact that the volume of a cell correlates to the amount of metabolic activity occurring within them, while the surface area of a cell correlates to flow rate of materials in and out of the cell. As we increase the volume of the cell, and therefore decrease the $\frac{S}{V}$ ratio, the cell has more metabolic activity, but does not have enough surface area for raw materials to flow into the cell and waste products to flow out. Therefore, cells always remain quite small, in order to have a high $\frac{S}{V}$ ratio.

3.3. Tools

In studying the biology of the cell, there are various tools we can use to aid in our research.

3.3.1. Microscopy

With some exceptions, single cells generally cannot be seen without the help of microscopy. There are two categories of microscopy that we are interested in for looking at cells: electron microscopy and light microscopy.

The **light microscope** is the one that you are familiar with from use in school. This microscope works by using visible light and a series of lenses to magnify images. With this type of

microscope we can usually have a detailed view of most eukaryotic cells.

On the other hand, we have the **electron microscope**. Electron microscopes can give us images of much smaller objects than we could visualize with light microscopes This has to do with the fact that electrons have a much shorter wavelength than light, and therefore, the electron microscope has much greater resolving power than a light microscope.

There are two factors that we are interested in when talking about the ability of a microscope to produce images, resolution and magnification. **Resolution** is the ability of a microscope to distinguish two objects, and **magnification** is how much a sample can be enlarged, the degree of which is measured by the ratio of the size of the image to the size of the original object.

3.3.2. Centrifugation

The centrifuge is another tool used by scientists to study the cell. We can blend up a solution of cells, destroying the membranes and thus placing all of the organelles free floating into the solution.

The centrifuge will spin at somewhere generally between 6-12 thousand rpm, and the heavier structures will separate to the bottom of the tube, while the smaller structures will move towards the top. This allows us to separate the organelles by weight.

3.4. Cells

There are two main types of cells that we encounter, the prokaryotes, and the eukaryotes. They differ in size, structure, functions, and the types of organisms they are present in. Before we look into features of cells unique to either of these two, we will look at features that exist in all cells.

The **plasma membrane** is the defining feature of a cell. It is what separates the cell from the outside world. This membrane consists of phospholipids, along with other molecules dispersed throughout it. We will discuss the specific structures and functions of the plasma membrane in greater detail later on.

The **cytoplasm** is a general term for the contents of the cell excluding the nucleus. Two of the main constituents which we find within the cytoplasm are the cytosol and the organelles. The **cytosol** is mostly water with some ions, molecules, and soluble macromolecules dissolved within it. **Or ganelles** are the nucleus and the complex structures within the cytoplasm.

3.4.1. Prokaryotes

Prokaryotic cells are the cells that make up the bacteria and archaea. These cells are very small, less than 1 micrometer in diameter. The organisms which consist of these cells are generally single-cell organisms.

Structurally, we find a series of interesting layers on the outside of the cell, protecting it from the outside world, and sometimes, specifically for pathogenic bacteria, protecting it from your immune system. First, directly outside of the membrane, prokaryotes often have a cell wall, a rigid structure giving shape to the cell. Second, some prokaryotes have a glycocalyx, a layer which either exists as a layer of slime or a more well formed layer, called a capsule. This glycocalyx exists outside of the cell wall and helps bacteria adhere to their environment, and also helps pathogenic bacteria evade host immune system defenses.

3.4.2. Eukaryotes

The eukaryotic cell is much larger, as well as more complex, than the prokaryotic cell. The most important difference we see within the cell is the presence of membrane-bound organelles.

3.4.2.1. Organelles

The most important organelle that is only found within eukaryotes is the **nucleus**. The nucleus is a large, centrally located, membrane bound organelle. It contains the **DNA** of the cell, which is found in the form of chromatin wrapped up into multiple linear **chromosomes**. The nucleus also contains nucleoli, (singular = nucleolus). The **nucleolus** is responsible for the synthesis of the two sub-units which form another very important organelle, the ribosome.

The **ribosome** is the organelle which is responsible for the synthesis of proteins. It takes in a strand of messenger RNA (mRNA) and creates a chain of amino acids, known as a polypeptide. It does this by reading the strand of mRNA three nitrogenous bases at a time. Each of the the potential three letter codes, called codons, correlate to one amino acid, which the ribosome acquires from a tRNA, and then adds to the growing poly peptide chain. A few codons do not correlate to an amino acid, instead acting as a stop signal, which, when read by the ribosome, cause the polypeptide chain to be released. Ribosomes

are found in two forms; free in the cytoplasm, or embedded in the endoplasmic reticulum.

The endoplasmic reticulum (ER) comes in two flavors: rough and smooth. The **rough endoplasmic reticulum** (RER) is a membranous organelle which is continuous with the nuclear envelope. It is called rough as it has embedded ribosomes within its membrane. The ribosomes synthesize proteins which are created in the center of the RER. This area which is completely enveloped by the membrane of the RER is called the lumen of the RER. After the proteins are synthesized, within the RER they are folded into their shapes and sometimes marked with certain chemicals in order to ensure they are correctly transported. Proteins are transported from the RER in vesicles which pinch off of the membrane. The proteins made in the RER are often membrane-bound proteins.

The **smooth endoplasmic reticulum** (SER) is continuous with the RER. It lacks ribosomes, and thus does not have the same rough appearance of the RER. The SER is responsible for:

- The detoxification of drugs and poisons
- Glycogen degradation in animal cells
- Synthesis of lipids
- Storage and release of Ca^{2+} ions

The **golgi apparatus** is the next stop for proteins after the cytoplasm or RER.This is often referred to as the "post office" of the cell. The golgi takes proteins and modifies them, and then sends them away in vesicles to their final destinations. The modifications are in the form of carbohydrates being added to the proteins. In plants, it also is responsible for the synthesis of some polysaccharides used in the cell wall.

Lysosomes are one particular product of the golgi. Lysosomes are vesicles whose proteins are hydrolytic enzymes. When a lysosome is secreted from the golgi, it is referred to as a primary lysosome. Once it fuses with another vesicle, in order to break down its contents, the new fused vesicle is referred to as the secondary lysosome.

Peroxisomes are organelles responsible for the oxidation of certain types of molecules, most importantly long chain fatty acids. One of the byproducts of this reaction is H_2O_2. The problem is that this hydrogen peroxide is dangerous to the cell. However, the peroxisome also has the ability to use this toxic hydrogen peroxide in other reactions within it in order to dispose of it.

Another very important organelle in eukaryotic cells is the **mitchondria**. This organelle is responsible for the synthesis of ATP via aerobic respiration. The mitochondria has two membranes, the outer and inner membranes. The inner membrane has infoldings called cristaea which increase the surface of that membrane. The area in between the two membranes is called the intermembrane space and the area enclosed within the inner membrane is the mitochondrial matrix. Later on, when we look at the metabolism chapter, we will see how these structural features aid in the metabolic processes which occur within the mitochondria.

3.4.2.2. Organelles Specific to Plant Cells

Plant cells have a few organelles that are not found within other types of eukaryotic cells.

Plastids are a class of organelles found in plant cells generally used in a storage capacity.

One such plastid is the **chloroplast**. This organelle is responsible for photosynthesis, the process by which plant cells create sugars from sunlight and carbon dioxide. It stores chlorophyll, which gives plants their green color. Inside the chloroplast, we also have thylakoids. These are flattened sacs which are kept in stacks called grana.

Chromoplasts are plastids which contain yellow or orange pigments.

The **central vacuole** takes up a large amount of an average plant cell's volume. It has two main functions, storage and maintaining **turgor pressure** against the cell wall (the pressure is responsible for pushing the cell membrane on to the cell wall).

Plant cells also have a **cell wall**. This wall is found directly outside of the plasma membrane and has a variety of roles. It:

- Provides support for the cell
- Acts as a barrier to infection
- Contributes to plant form by directing cell expansion

Embedded through the cell wall are channels called **plasmodesmata** which connect cytoplasms of adjacent plant cells.

3.4.3. The Cytoskeleton - Under Construction

The cytoskeleton is part of the cell that provides structure and allows for cell movement.

There are three main elements of the cytoskeleton: microfilaments, intermediate filaments, and microtubules.

3.4.4. The Extracellular Matrix

Animal cells do not have cell walls, however they do sometimes have an extracellular matrix. The extracellular matrix (ECM) is the network of connected proteins and carbohydrates that exists outside of many types of animal cells. Two of the main components of the ECM are proteoglycans and collagen.

Collagen is a protein which exists in the ECM. It is present in, among other places, skin and cartilage. It functions to hold cells together in tissues. **Proteoglycans** are glycoproteins with long carbohydrate side chains. These function to filter materials passing between tissues, as in the kidneys.

3.4.5. Junctions in Animal Cells

Animal cells have three different types of junctions between them that serve different roles.

3.4.5.1. Tight Junctions

Tight junctions function to make a watertight seal, especially in epithelial cells. Seen in epithelial tissue

3.4.5.2. Desmosomes

Another type of junction in animal cells is the desmosome. This junction functions to link cells tightly, however materials can move between the cells. It also provides mechanical stability (i.e. it is found in skin).

3.4.5.3. Gap Junctions

The last type of junction is the gap junction. The gap junction is the animal analogue of plant plasmodesmata. It consists of channels that run between cells, allowing substances to go between cells. It is found in the heart, these allows ions to flow so that muscle cells beat in unison.

4. Membranes and Signaling

The cell membrane is an extremely important part of the cell. It serves to be the interface through which anything passing into or out of the cell must use. This gives it an important role in many domains of cell function that require interaction with the outside world.

Underlying much of the cell membrane's ability to regulate traffic in and out of the cell is its **selective permeability**. This means that some substances can pass through it, while others cannot. Generally, due to the phospholipid bilayer structure of the membrane, non-polar substances can generally move through the membrane on their own, while polar molecules and ions need the help of different proteins to pass through the membrane.

We will be looking at not only the cell membrane, as the structures and functions we will look at are found throughout not only the cell membrane, but the entirety of the endomembrane system as well.

The different membranes of the cell are not just purely made of phospholipids. There are a variety of other lipids and proteins which make up the membrane.

4.1. Membrane Fluidity

Membranes also need to be fluid. This means that all of the proteins and lipids of which they consist are able to move past one another.

Altogether, this model of a membrane where we have different types of macromolecules, which are able to move around is called the **fluid mosaic model** of the membrane.

The fluidity of membranes is affected by their composition. There are two main compositional factors involved in this. The first factor is the presence of **cholesterol**. At regular temperatures, cholesterol blocks movement of phospholipids, thus increasing the fluidity of the membrane. However, at lower temperatures, the cholesterol being wedged between phospholipids stops the phospholipids from being able to solidify because they can't as tightly together. The other factor is the degree of saturation throughout the hydrocarbon tails on the lipids in the membrane. If there is a high percentage of fatty acids in the membrane that are saturated, the membrane will be less fluid, as these pack tightly together, while a high percentage of unsaturated fats will prevent the lipids from packing together and will increase the fluidity of the membrane.

4.2. Membrane Proteins

The proteins of membranes are responsible for some of their more interesting functions. Throughout the different membranes in the cell, we find different proteins, with different functions.

The first main division of membrane proteins are the integral proteins vs. the peripheral proteins. Integral proteins are those who find themselves within the central region of the membrane, while peripheral proteins are on only the surface of the membrane. Within the integral proteins, we see many that not only exist in the center of the membrane, but actually span from one side of the membrane to the other, these are called transmembrane proteins, and these are interesting because some can carry, or allow passage, of substances that otherwise could not pass through the hydrophobic core of the membrane from one side to the other.

4.3. Transport

4.3.1. Passive Transport

The first major function of the membrane we will look at is transport through the membrane not requiring energy, also known as passive transport. In this mode of transport, particles are moving by diffusion. **Diffusion** is the process by which a substance moves down its concentration gradient. When substances diffuse, we see three important factors which affect the rate of diffusion.

- The size of the particle. Smaller particles diffuse quicker.
- The temperature. The hotter the temperature, the faster diffusion will occur.
- The magnitude of the concentration gradient. The steeper the concentration gradient, the faster diffusion will occur.

Another important concept in diffusion is **osmosis**. Osmosis is the diffusion of water. The concentration of water is higher where the concentration of dissolved solutes is lower. Osmosis becomes interesting when we have a situation where the solutes cannot diffuse through the membrane while the water can. In the specific case of cells, depending on the difference in solute concentration, we see three types of situations:

- Hypertonic: Hypertonic solutions are where there is a greater concentration of solutes outside the cell compared to inside. This leads to water leaving the cell via osmosis. This situation is generally not beneficial to any type of cell.
- Isotonic: Isotonic solutions are where there is an equal concentration of solutes outside the cell and inside. This leads to no net movement of water due to osmosis. This situation is generally not beneficial to any type of cell.
- Hypotonic: Hypotonic solutions are where there is a lower concentration of solutes outside the cell compared to inside. This leads to water entering the cell via osmosis. This situation is generally beneficial to cells with cell walls, such as plant cells. This is important as the pressure from the constant inflow of water puts pressure against the cell wall, which keeps the cell rigid, and due to the cell wall, the cell will not burst.

There are two major ways passive transport can occur:

- Non-polar substances are generally able to diffuse freely through the membrane as they are able to pass through the hydrophobic core with ease, these are said to move by *simple* diffusion.
- Polar substances cannot move freely through the membrane. These molecules require proteins to act as either carriers or channels in order for them to pass through the hydrophobic core of the membrane. This process is called *facilitated* diffusion .

In facilitated diffusion, substances move through the core of the protein, which is hydrophilic. This ensures that the polar substances will be able to move through them unhindered. The two subtypes of these proteins are the carrier proteins and the channel proteins. Channel proteins provide a pathway for substances to flow through, while carriers accept the molecule to be transported on one side, and then change conformation in a way which will bring the molecule to the other side of the membrane.

4.3.2. Active Transport

The process of active transport encompasses any type of transport which requires energy. This energy generally comes in the form of ATP releasing its terminal phosphate group, which then attaches to the protein, forcing a conformation change. The proteinchanging shape allows it to push substances against their concentration gradients. Within active transport we have primary and secondary active transport.

Primary active transport is the simpler of the two, where we simply push substances in a direction.

Secondary active transport is a two step process. First, we actively transport a substance

against its concentration gradient. This in turn creates a concentration gradient as we now have a large number of the substance on one side of the membrane. These will now diffuse via facilitated diffusion back across the membrane to where they started.

What is the point of this?

The trick is that another substance also wants to travel the same way as the material is diffusing. The material we pumped to one side of the membrane which is now flowing back, will act to allow the transport of the second substance across the membrane, which would not be possible if the first substance were not diffusing as well. Hence, the cell creates an artificial gradient in order to ensure it is constantly diffusing.

4.3.3. Bulk Transport

Bulk transport encompasses transport processes where we have large amounts of material crossing the cell membrane in vesicles. This is an example of active transport, as ATP is required for this process. There are two types of bulk transport, exocytosis and endocytosis.

Exocytosis is where the vesicle originates from within the cell, fuses with the cell membrane and spills its contents into the extracellular space. This can either rid the cell of waste or secrete useful products.

Endocytosis is the opposite, where vesicles form from the plasma membrane to bring in substances. There are three versions of this process.

- Phagocytosis - The cell brings in large solid chunks of material into the cell.
- Pinocytosis - The cell brings in liquid from the extracellular space, in order to acquire the molecules dissolved within.
- Receptor Mediated Endocytosis - A specific *ligand* matching with a receptor on the extracellular side of the plasma membrane precedes the endocytotic process.

4.4. The Cell's Response to Environmental Signals

Cells receive signals from different sources:

- Autocrine - Cell receives a signal from itself.
- Paracrine - Cell receives a signal from nearby cells. Signal spreads via diffusion.
- Juxtacrine - Cell receives a signal from cells in physical contact with it. Signaling molecules are usually bound to cell surfaces.
- Hormones - Cell receives signal from far away in same organism. Hormones travel through circulatory system of animals or vascular system of plants.

Once a cell receives a signal, we see the activation of a **signal transduction pathway**, which is a series of chemical reactions and changes within the cell which constitute the cell's response to the signal. We often see allosteric regulation as part of pathways. This is where the 3D shape of proteins is modified via the attachment of a molecule to an area of the protein besides the active site.

The end response of a signal transduction pathway can be as ephemeral as activation of a signal enzyme to as consequential as an alteration to gene expression within the cell.

4.4.1. Receptors

We have two types of receptors based on their location, intracellular and membrane receptors. We can also look at the different types of receptors in terms of their functions.

4.4.1.1. Membrane Receptors

These receptors are on the surface of the cell and react to *ligands* which bind to a site on them. One important idea is that the bonding of ligands to receptor proteins is reversible, meaning that they may detach, and the protein will return to its original conformation.

There are three categories of cell membrane receptors that we will study in this course:

- Ion Channel Receptors - These receptors allow for the passage of ions to pass in and out of the cell. These receptors are said to be "ligand gated", which means that without the attachment of a ligand, the channel will not function.
- Protein Kinase Receptors - These receptors also change conformation upon the binding of a ligand. Here, the binding of a ligand allows the protein to expose a region on the cytoplasmic side used for catalysis. The *kinase* part of the name lets us know that the reactions that they catalyze will involve the addition of a phosphate group to another protein. Think about the implications for signal transduction pathways...
- G Protein-Linked Receptors - Upon a ligand attaching to the receptor on the outside facing domain of this protein, G protein-linked receptors expose a cytoplasmic region capable of

bonding a G protein, which is a mobile protein partially embedded in the lipid bilayer and partially exposed on the cytoplasmic side of the cell membrane. The molecules G proteins are able to bond to include:

- G Protein-Linked Receptor
- GTP and GDP
- An effector protein

Once activated, the g protein-linked receptor exchanges a GDP for a GTP with the g protein. The g protein now changes shape and is able to activate an effector, passing on the signal.

This has been an overview of membrane receptors. While they come in different shapes and sizes they have a few things in common, mainly concerning the end result of what they do, whcich is take the signal from the outside of the cell, to cause some change within the cell.

4.5. Signal Transduction

In the process of signal transduction, a cascade effect occurs, where one protein changes another, which changes yet another protein and so on and so forth. The goal of the process here is to pass on the signal to effect some change in the cell. In this proecess, as the signal cascades, it can both **amplify** and **distribute** throughout the cell, meaning the strength of the signal increases over time, and the signal can branch, in order to cause multiple effects.

4.5.1. Cell Functions Change in Response to Signals

Let's look at the different ways the cell can change from the signal.

- When ion channels open, a charge builds up across the membrane, and the build up of a membrane potential has important consequences in nerve and muscle cells.
- Alterations in gene expression occur via up or downregulation, thus altering the level of the gene product (protein) present in the cell.
- Alteration of enzyme activity is where a signal causes a change in behvaior in enzymes within the cell.

Note that the same signal can cause different effects depending on what type of cell it is acting on.

4.5.2. Second Messengers and Signal Transduction

Second Messengers are small molecules which

5. Energy Production

This chapter talks about the different parts of the energy production pathway in the cell. The interconnected chemical pathways we will study in this chapter include photosynthesis, oxidative phosphorylation, the citric acid cycle (AKA: Krebs Cycle), electron transport chain, glycolysis and fermentation. We will see that these different pathways have many things in common, and how the end products of one pathway will be the starting material for another.

5.1. ATP and Reduced Coenzymes

Let's talk about APT and NADH. As we talk about energy, remember the laws of thermodynamics: energy cannot be created or destroyed, all the reactions we talk about simply *convert* energy from one form to another.

5.1.1. ATP

ATP is the energy currency of the cell. It is readily available for use in a wide variety of energy requiring applications in the cell. ATP stands for adenosine triphosophate, which is an example of a nucleotide triphosphate, meaning that it consists of three phosphate groups, the sugar ribose, and the nitrogenous base adenine.

The relevant parts of the molecule are the bonds linking the phosphate groups together. The bond holding the terminal phosphate to the middle phosphate, as well as the bond holding the middle phosphate to the inner phosphate have a great deal of energy stored within them.

If the bond holding the terminal phosphate is broken, we are left with ADP (adenosine diphosphate) and one free phosophate, and a great deal of energy is released. This type of chemical reaction is referred to as being *exergonic*, meaning that energy is released, which can be contrasted with *endergonic* chemical reactions, where energy is added into the reaction in order for it to occur.

You have alredy seen many examples of ATP hydrolysis being used to provide energy. All active transport processes that we saw in the previous chapter utilize ATP hydrolysis to provide energy for the reactions that are occurring.

References

David Hillis, David Sadava, Craig Heller, and Mary Price, *Prinicples of Life for the AP course, 2nd ed.* W.H. Freeman (2014).