Delve AP Biology
Lecture 1: 9/18/11
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Today's Agenda:
I. Class Intro
II. Introduction to Biology: What is Life?
III. Review of Chemistry
IV. The Importance of Water to Life
V. Quick Overview of Organic Chemistry
VI. Biological Macromolecules

I. Class Intro

Review of class syllabus
Structure of class: divided into units of Biochemistry, Cell Biology, Molecular Biology, Genetics, Organisms, Ecology [see syllabus for more details]
General scheme: We are starting off with small-scale science of molecules, building up to organ systems and ecosystems

Our expectations
You should keep up with the material, put in an earnest effort to read, and do the work we assign
You should come to class and be ready to participate while in class
We want you to focus and try your best
Please do not distract yourself and others

Class policies
Homework is expected to be done, with a huge emphasis on doing the readings
Attendance is very important and you should email us if you expect to miss class
No formal grades are given
Feel free to talk to us or email us if you have questions
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Your expectations
You can always expect us to answer your questions and respond to your emails
You should be able to influence the class, ask us to change the pace of the class or review things again if they are not clear
You should know how you are doing in this class, feel confident in your preparation with the material

II. Introduction to Biology: What is Life?

What defines life? How do we know something is alive?
Properties of life: order, adaptation, response to environment, energy use, regulation, growth/development, reproduction

How do we observe life to be organized?
Biological hierarchy: biosphere → ecosystems → communities → populations → organisms → organ/organ systems → tissues → cells → organelles → molecules

In this course, we will see how a molecule like DNA both makes up a crucial part of cells, but also determines their behavior and survival. Correspondingly we will see how cells can interact with each other to make up more complicated organisms. Then within the ecosystem, we will observe how organisms interact in a way that creates a dynamic and thriving biological community. We will work on several levels of scale: starting out small with **biochemistry** and working our way towards **ecology**.

Emergent properties: new properties becoming apparent because of how multiple parts are arranged and interacting

Reductionism - reducing a complicated system to its component parts, which are easier to study and understand

- How we can study complex biological systems
- This is all part of a growing field of **systems biology**, understanding how different parts fit together and act dynamically to change the behavior of the whole system

"Themes" in biology - cell, inheritance of information, emergent properties of systems, regulation, interaction with environment, energy and life, unity/diversity, evolution, structure and function, scientific inquiry, science/technology/society

III. Brief Review of Chemistry

We will start on the smallest scale, understanding the behavior of tiny parts of biological systems We assume that you already know some chemistry and that this is not brand new, if it is, you will need to do some additional review

Matter: "stuff" that makes up everything. Think of it as the actual particles in everything and not like weight or volume. Matter is made of atoms, which are made up of neutrons, protons, and electrons
Elements: matter with a unique identity [ex: hydrogen, oxygen]. The atoms of each element differ by the number of protons, and each element behaves differently in terms of its chemistry
Compounds: elements joined together [ex: 2 hydrogen atoms joined to 1 oxygen atom makes water, which is a compound]

Elements that essential to life: ~25 total

- Include carbon, oxygen, hydrogen, nitrogen, calcium, phosphorous, potassium, sulfur, sodium, chlorine, magnesium
- The most prevalent elements are **C, O, H, N**
- **Trace elements**: elements that are important to some species of life, but present in only very small amounts [ex: iron, iodine]

Dalton: atomic mass unit, corresponds with $^{1}/_{12}$ mass of a single neutral atom of carbon, about 1.66 x 10^{-27} kg [very small amount of mass!]. One dalton is approximately the mass of one proton or one neutron. We will use this frequently to discuss the mass of biomolecules like proteins.

Other chemical terms you should know: atomic number, mass number, atomic mass
Isotopes: different forms of the same element. Isotopes are atoms of the same element with varying numbers of neutrons [remember: atoms of the same element have the same number of protons]. Isotopes can be radioactive if the nucleus decays and emits particles/energy. Isotopes are used frequently in medicine and research science to "tag" molecules.

Atoms as particles with mass also have energy. This energy is inherent within the way an atom is organized [a positively-charged nucleus with negatively-charged electrons around it].

- Electrons have potential energy from their arrangement as a negatively-charged particle relative to a very large, positively-charged nucleus
- The farther away an electron is, the more energy it takes for it to be stable/lasting

Energy: the capacity to cause change or "do work"

- The use of energy is very important for life
- Energy comes in many forms [ex: potential, kinetic, etc.]
- Potential energy is due to the location or structure [ex: potential energy is stored in chemical bonds, and this energy is released when the bonds are broken]
- Kinetic energy is due to motion

Energy levels: energy state of an atom, determined by the potential energy of its electrons. If electrons absorb energy, they become "excited" and they can go to a higher energy level farther from nucleus. Conversely, if electrons emit energy, they will fall down to a lower energy level and be closer to the nucleus. Since the distance of electrons from the nucleus determines energy levels, **electron shells** are used to represent the approximate distance. **Electron orbitals** give a better sense of actual distance, but they are still not exact.

Chemical behavior results mainly from the activity of the electrons and whether an atom wants more electrons, fewer electrons, or neither. The electrons that are lost/gained can only be in the outermost level. These are the **valence electrons** in the **valence shell**. Atoms want full electron shells with paired electrons, and they will interact and form bonds to achieve this ideal electron configuation.

Chemical bond: joins atoms together to form a compound. **Covalent bonds** come from sharing electrons between atoms to make a molecule. In a single bond, atoms share one pair of electrons. They can share multiple pairs to form multiple bonds [ex: 2 pairs in a double bond].

Electronegativity: the affinity of an element for electrons, AKA how badly an atom wants electrons. Periodic trend: the elements in the top right corner of the periodic table are generally the most electronegative. Fluorine is the most electronegative element.

Polarity: unequal sharing of electrons in a molecule. This unequal sharing arises from the electronegativity of different atoms. The electrons shift towards one side more than another, leading to partial charges within the molecule even if the entire molecule is neutral. For example, oxygen is more electronegative than hydrogen. In a water molecule, the oxygen will "want" the electrons more and "pull" them closer. This leads to partial charges on the water molecule [also called **dipole moment**]. The oxygen has a partial negative charge and the hydrogens have a partial positive charge, making water a polar molecular. However, a water molecule as a whole is neutral.

Ion: atom or molecule with a charge [cation = positively charged, anion = negatively charged] Ions result from atoms giving up or gaining an electron [atoms are neutral].
Ionic bond: a bond resulting from the attraction of opposite charges [ex: table salt is NaCl, Na+ is attracted to Cl-]. Ionic compounds can also be called salts.

Weak chemical bonds [not ionic or covalent] are still extremely important to the chemistry of life
Hydrogen bonds: attraction between hydrogen and electronegative atom [F, O, N] attached to much less electronegative atom, thus partially negatively charged. [Ex: the oxygen atom in a water molecule is partially negative, attracts a hydrogen atom on another water molecule].
van der Waals interactions: attraction of various dipoles where each dipole is caused by shifts in electrons within a molecule. These interactions can be transient or permanent.

Molecular shape and structure: these are determined by the atoms and molecules that make up a biomolecule and how they interact/bond. The structure is essential for understanding how biomolecules recognize each other, catalyze reactions, form even larger structures, etc.

Chemical reactions and chemical equilibrium: very important to understand as they are everywhere [metabolism, building new biomolecules, storing and harvesting energy, etc.]

IV. The Importance of Water

It is important to understand the significance of chemistry as not just acting on a small level, but as enabling higher level features. Water is extremely important to life: it is the environment life exists in, it differentiates our planet from others, and it is what we are made of.

Water is a **polar** molecule: O is the more electronegative atom. This results in a negative partial charge on the O, positive partial charge on H's. This also leads to transient **hydrogen bonds** between water molecules [from the attraction between the partial negative charge of O to the partial positive charge of H on another molecule]. Within liquid water, the molecules are constantly forming/reforming hydrogen bonds with their neighbors.

Emergent properties of water: the special properties of water come from its chemical structure. Its hydrogen bonding and its polarity result in the following:

- **Cohesion**: water molecules "stick" to each other
- **Adhesion**: water molecules "stick" to polar surfaces
- **Surface tension**: how water molecules at the surface/edges of the liquid hold together [ex: water droplets on a hard surface]. This is an example of cohesion.

- **Temperature moderation**: water has a **high specific heat capacity**, which is the amount of heat it takes to raise the temperature of one gram of water by 1 K [the specific heat of water is 4.184 J/g•K]. The high specific heat of water leads to the ability of bodies of water to maintain a relatively stable temperature.
- **Evaporative cooling** is the mechanism by which living things can cool themselves
- **Insulation by ice**: ice is less dense than water, so it floats. Hydrogen bonds transiently form in liquid water and molecules are close together. When water freezes, hydrogen bonds become stable, which forces the water molecules to space out and arrange themselves nicely in a lattice. Ice floating on top of body of water insulates the liquid water below it, keeping the organisms living in the water alive.

Note: There is a distinction between **heat** and **temperature**. Heat is all of the kinetic energy stored in the molecules of a substance. Temperature is the average kinetic energy of the molecules.

Solvent: the liquid substance that dissolves another substance, the **solute**, to form a homogeneous **solution** of the two substances

- On a molecular scale, there is a **hydration shell** [a shell of water molecules] surrounding a dissolved solute particle
- Not all substances can be dissolved in water
    - **Hydrophilic** substances like sugars, salts can dissolve. Some hydrophilic substances do not dissolve but still interact with water
    - **Hydrophobic** substances like oil, butter, fats cannot dissolve

Acids/Bases

Water molecules interact with each other, molecules dissociate by donating and accepting protons or positive hydrogen ions from each other. This leaves a hydronium ion H_3O^+ and hydroxide ion OH^-. There is only a small concentration in pure water, but influences the pH or acidity/basicity.

$H_2O + H_2O \Rightarrow H_3O^+ + OH^-$

[the reverse reaction also occurs at the same rate in equilibrium]

Acid: contributes to the hydrogen ion or proton concentration of the solution

Base: reduces the hydrogen ion concentration of the solution

Acidity is measured in **pH = -log[H_3O^+]** where [H_3O^+] usually is 10^{-7} M in pure water so pH = 7 for water [pH = 7 is neutral]. A -log[x] means that a higher H_3O^+ concentration gives a lower pH, and a lower H_3O^+ concentration gives a higher pH.

The chemistry of life requires particular conditions [certain temperature and pH range] that allows reactions necessary for life. **Buffers** exist to stabilize pH in nature. They can give or accept hydrogen ions to try to keep H_3O^+ concentration and pH stable.

In Summary:

Water is the solvent for life because of its important chemical properties. It is a polar molecule with a dipole moment. This allows hydrogen bonding and makes water a good solvent. Water also has a large surface tension and has cohesion/adhesion. Its high specific heat helps regulate the temperature on Earth. It expands when frozen, so ice is less dense than liquid water.

V. Organic Chemistry

A compound is classified as "organic" if it contains **carbon and hydrogen** [some people say that a compound is considered "organic" if it contains carbon, but there are some exceptions like CO_2]. Carbon is an important element with **4 valence electrons**. Because there are 4 valence electrons, carbon can form up to 4 covalent bonds [because carbon wants to fill its electron shell with the closest noble gas configuration, which is 8 electrons]. Carbon-carbon bonds are very strong and stable. This allows for diverse molecules of different shapes and sizes [ex: benzene rings, long carbon chains, etc.]

VI. Biological Macromolecules

A macromolecule is a very large molecule [polymer] made of smaller, recurring molecules [monomer]. Monomers are linked together to make polymers through a **dehydration/condensation reaction** [H and OH are combined to release one water molecule]. Polymers are separated into monomers through **hydrolysis** [add one water molecule, which splits into H and OH]. There are 4 major classes: carbohydrates, lipids, nucleic acids, and proteins.

Carbohydrates [polysaccharides, sugars]

A carbohydrate is an organic macromolecule containing only **carbon**, **hydrogen**, and **oxygen**. They are made of monomers called **monosaccharides** [ex: glucose, fructose in fruits]. These monosaccharides are joined together by a dehydration/condensation reaction. The covalent bond between two monosaccharides is called a **glycosidic linkage**. Two monosaccharides form a **disaccharide** [ex: sucrose/table sugar = glucose + fructose, lactose = glucose + galactose]. Many monosaccharides joined together are **polysaccharides** [ex: starch, cellulose]

Carbohydrates have several important functions:

Energy source

- Glucose is needed in cellular respiration, which converts the chemical bonds in glucose into energy

Longer-term storage of energy

- Starch [plants] is a big energy source for humans! [ex: potatoes, rice, wheat, etc.] Starch is made of 2 different polysaccharides- **amylose** and **amylopectin**. Amylose is linear, so it has a tightly packed structure. Amylopectin is highly branched. Different starchy foods have different ratios of amylose to amylopectin.
- Glycogen is the secondary long-term storage of energy in animals [the primary long-term storage of energy in animals is fat]

Structural

- Cellulose in plant cell walls. Cellulose is actually made of the same monomers as starch [glucose], but the monomers have a different spatial arrangement. Starch has a helical structure, but cellulose is linear. Hydrogen bonds between the cellulose polysaccharides strengthens the cell wall
- Chitin in insect exoskeletons

Interesting fact: all mono/disaccharides end in **-ose**

Lipids

It is harder to classify lipids, because they comprise a broader group of macromolecules than the other 3 classes. One general "definition" of lipids is **small hydrophobic molecules**. Lipids include **fats**, **phospholipids**, **hormones**, some vitamins [fat-soluble]

Fats [energy storage]

- Triglycerides: The basic structure is fatty acids [long hydrocarbon chains] attached to a glycerol. The hydrocarbon chains are nonpolar, so they are hydrophobic.
- The fatty acid chains can be saturated or unsaturated. [The word "saturated" refers to how many hydrogens can be bonded to the carbon backbone chain.]
    - When a hydrocarbon is saturated, all of the carbons are singly bonded to each other
    - An unsaturated hydrocarbon has some carbon-carbon double bonds. The double bonds can cause "kinks" in the fatty acid chain.

Phospholipids [cell membrane]

- The cell membrane is a lipid bilayer. The structure of the phospholipid determines the function of the cell membrane. A phospholipid consists of a hydrophilic head and 2 hydrophobic tails.
- The hydrophilic head is made of a phosphate group, which is charged. Since it is charged, it wants to be surrounded by water [because of water's dipole moment].
- The hydrophobic part is made of 2 fatty acid tails, which are nonpolar
- Therefore a phospholipid is **amphipathic**, which means it has a hydrophilic and a hydrophobic region. The amphipathic quality of a phospholipid allows it to spontaneously form a lipid bilayer membrane in an aqueous environment.

Hormones [signaling]

- Some hormones are classified as lipids. These include steroids, cholesterol, testosterone

Nucleic Acids (DNA and RNA)

Nucleic acids encode genetic information

The structure of nucleic acids

- The monomers are nucleotides. Each nucleotide has 3 basic components: **phosphate group**, **5-carbon sugar**, and a **nitrogenous base**. The carbons are numbered: #5 is attached to phosphate group and #3 has a OH group
- To connect the nucleotides, a dehydration reaction happens between the phosphate group and OH group, and a **phosphodiester bond** is formed
- The phosphate and 5-carbon sugar form the backbone of the nucleic acid. There is a polarity to the backbone: 5' [the phosphate group] to 3' [the OH group]. Nitrogenous bases interact with each other through hydrogen bonds

Differences between DNA and RNA

- DNA is a double stranded helix [stable], RNA is single stranded [not as stable]
- The 5-carbon sugar is a **deoxyribose** in DNA [only has H on #2 carbon], while the 5-carbon sugar is **ribose** in RNA [has OH on #2 carbon]
- Nitrogenous bases in DNA: **adenine**, **thymine**, **guanine**, **cytosine**. The bases are the same in RNA except **uracil** is used instead of thymine [they look very similar]

- Nitrogenous bases are divided into 2 groups: **purines** [2 rings, A and G] and **pyrimidines** [1 ring, T, U, C]. A purine must always be paired with a pyrimidine [purine-purine pairing is too big, pyrimidine-pyrimidine pairing is too small]

Proteins

Proteins have many different functions, but they all have the same basic structure

Structure

- The monomers are **amino acids**, and they are joined together with a **peptide bond**. The polymer is sometimes called a **polypeptide**. The condensation/dehydration reaction is catalyzed by the ribosome.
- There are 20 amino acids. They all have the same basic structure:
    - There is an **amino (N) terminus** and **carboxyl (C) terminus**, and this forms the backbone [N-C-C-N-C-C- etc.]
    - There also are **R groups**. The R groups are what make each amino acid unique. The R groups also dictate the reactivity of each amino acid [hydrophilic, hydrophobic, or acidic/basic]
- There are **4 levels of protein structure**
    - Primary: unique amino acid chain [which is synthesized from the genetic information encoded in DNA/mRNA]
    - Secondary: alpha helices and beta pleated sheets. These are formed from hydrogen-bonding interactions in the backbone
    - Tertiary: 3D conformation of the polypeptide chain, formed from interactions between R groups [some interactions include hydrogen bonds, disulfide bonds, Van der Waals, hydrophobic interactions, etc.]
    - Quaternary [only when the protein is made of at least 2 polypeptide chains]: Interactions between polypeptide chains [classic example: hemoglobin, which carries oxygen in red blood cells, is made of 4 polypeptides]

Functions

- Enzymes/catalysts
    - Ex: amylase catalyzes the hydrolysis of glycosidic bonds in starch [found in saliva]
    - Note: all enzymes end in -ase
- Structural
    - Ex: actin subunits form microfilaments, one of the 3 components of the cytoskeleton. The microfilaments help the cell maintain its structure, change its shape, and move.
- Cell signaling, signal transduction
    - Cell signaling is when a molecule from outside the cell activates a membrane receptor, which then causes a cellular response
    - Ex of signaling molecule: insulin and glucagon, located in the blood plasma [secreted by pancreas]
    - Ex of membrane receptor: insulin receptor and glucagon receptor, located on the cell membranes of liver and muscle cells
    - Insulin is a hormone [remember that some hormones are lipids, and some are not. In this case it is a protein]. Insulin and glucagon regulate glucose levels in blood.

- When there is a lot of glucose in your blood [like right after you eat a meal], insulin binds to its receptor and the cell takes in glucose and stores it as glycogen [carbohydrate, energy source].
- When glucose levels in your blood fall, glucagon binds to its receptor and the cell converts its glycogen into glucose and releases it into the bloodstream.
- When insulin does not work properly, blood glucose levels rise. This causes diabetes