Basics of Chemistry: Atoms and Molecules

WARNING!

Ignoring This Material is Hazardous to Your Bio101 Grade!

Ignoring This Material Will Impede Your Education!

You can do this: these are the basics! Trust me!

GOOD NEWS!

Learning this Material is Beneficial to Your Bio101 Grade!

Learning This Material Will Have Lasting Benefits in Your Science Education and Career!

You can do this: have a growth mindset!

HOMEWORK ASSIGNEMNT #1 (Due Sept 5) is derived directly from this document

This document provides a review of the very basic chemistry that you will need to know in order to succeed in Biology 101 this semester. You should have a firm command of all the bold terms and concepts in this document. **This document is the basis for Homework Assignment #1.** If you can complete HW Assignment #1 without consulting this or any other sources, then you are in command of this information. If not, study it more and attempt the assignment again.

Homework Assignment #1 is due on Wednesday, September , 5 at the BEGINNING of lecture. HW Assignment #1 is worth 50 points (6.25% of your final grade). The point value of this homework, in addition to the importance of this material for your success in Bio101, means that **you must NOT IGNORE THIS MATERIAL!** I implore you to begin this assignment during week 1 of class, and complete it over the first weekend (we do not have class on Monday Sept 3).

As always, if you need assistance I invite you to take advantage of my office hours or email me. Your tutor is a tremendous resource for this as well!

You can do this! You must do this!! You WILL do this!!! Have a positive attitude and a growth mindset as you navigate this material. Work in teams if you wish, but understand this material.

Basics of Chemistry: Atoms and Molecules

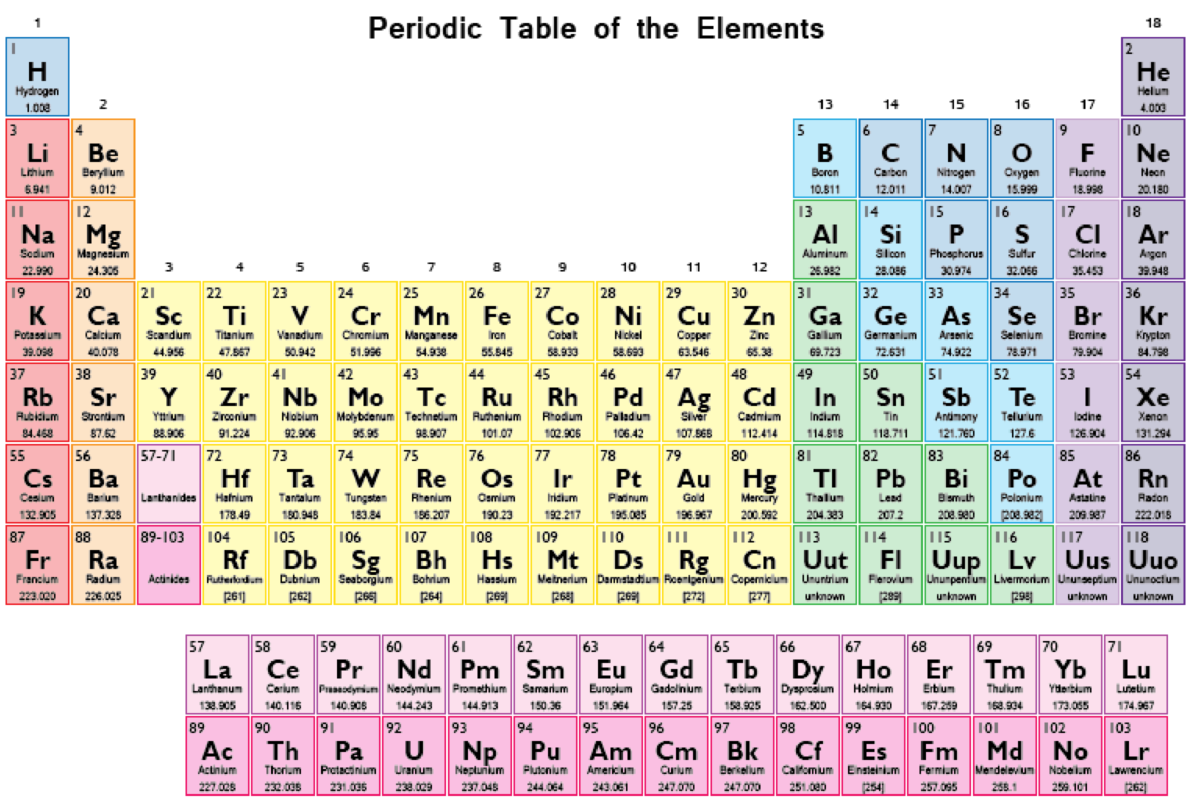
Part I: Matter and Elements
Living organisms - and <u>all</u> solids, liquids, and gasses on Earth - are comprised of **matter**

Matter: anything that occupies space and has mass. All matter is made of 1 or more of the **elements**.

Element: components of matter that cannot be broken down (turned into a new or different element) by ordinary chemical means (but can combine to make new substances).

There is a finite variety of elements from which all matter is constructed, and they are neatly arranged on the periodic table of the elements.

Within each cell of the periodic table, you need to be able to identify two pieces of information: 1) the atomic symbol (this is the 1 or 2 letter symbol), 2) the atomic number, which is the number in the upper portion of each cell (more on this below). You should know the elements represented by the following symbols: H, C, N, O. What are these elements? What is the atomic # of each?



VIDEO: https://www.youtube.com/watch?v=0RRVV4Diomg (0:00-5:00)
The first five minutes of this video provide a brief and incredible history of the periodic table! Watch the first five minutes if you so desire, but do NOT get bogged down in the material after minute #5, we will not discuss this.

Part II: Atoms

The smallest tiny bit of matter that an element can be reduced to is an **atom**. Alternatively; **Atom**: The smallest unit of matter that retains the properties of an element.

Atom: word origin "a" (not/non) + "tom" divide = non dividable. Indicates cannot be divided (few noteworthy exceptions…).

Atomic structure

All atoms are built from (for the most part…) 3 different **subatomic particles**:
1) **Protons**
2) **Neutrons**
3) **Electrons**

Here's what you need to know about subatomic particles (protons, neutrons, and electrons) for Biology 101 in Fall 2018:

1) **Protons**:
- Have a positive (+) charge
- Are located in the atomic nucleus (do not confuse this with the cell nucleus of eukaryotes!)
- **Atomic number** = number of protons in an atom (this number appears in the upper right corner of each element in most periodic tables)
- The element to which an atom belongs (i.e., the type of element an atom "is") is determined by the number of protons in the nucleus (i.e., the atomic number).

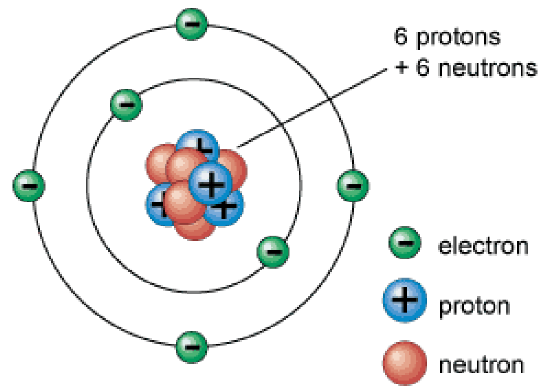
2) **Neutrons**:
- No charge
- Are located in the atomic nucleus

3) **Electrons** (notation: $\mathbf{e}^-$)
- Have a negative (-) charge.
- Orbit around the atomic nucleus in **valence shells** (also called orbitals)
- The maximum number of electrons that a in a valence shell can contain is as follows:
    - ➢ The innermost valence shell (i.e., the orbital closest to the atomic nucleus) can accommodate a maximum of 2 e^- (remember, the symbol for electron is $\mathbf{e}^-$)
    - ➢ All other valence shells (in this class) can accommodate a maximum of 8 e^-
- Occasionally, atoms in close proximity share or transfer electrons. The sharing or transferring of electrons results in chemical bonds between atoms. The atoms bonded together are now part of a molecule. Bonds and molecules are very important, and we will discuss them below!
- The # of electrons in an atom's outer valence shell determines whether or not it will form a bond with another atom, thereby forming a compound (more below).

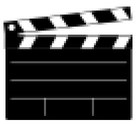
More on this below

BTW: nearly all individual atoms contain equal #'s of protons, neutrons, and electrons…(exceptions are isotopes…read more about these below)

At right is a model of a carbon atom. This is called a Bohr model, and it depicts the subatomic particles in their general location in the atom. Note that the atomic # of C is 6 (see the periodic table above), and we therefore place 6 protons, neutrons and electrons in this atom (we will always assume equal numbers of protons and neutrons, but this is not always valid). Note that two electrons are in the innermost orbital (the innermost e^- orbital can contain a max of two), and the remaining four are in the next orbital out from the nucleus.



Carbon atom



VIDEO: https://www.youtube.com/watch?v=tc9tEUqUmKw
The following video demonstrates the how one draws a Bohr model of an atom using the atomic number found on the periodic table. You should be able to readily do this for O, C, N, and H. Note especially the number and location of protons, and the number and location of electrons in their valence shells. (Ignore the part about atomic mass and neutrons, we won't deal with either in this class).

Part III: Atoms bond together and form compounds (aka molecules)

Some elements exist in nature in their pure form (e.g., gold (Au), silver (Ag), oxygen (O)… Can you find these on the periodic table above? How many protons does each have?) Needless to say, however, there are many more types of matter that exist in nature than the elements in the periodic table (e.g., water, H_2O). So, where do these different types of matter "come from" (that is to say, how are they formed?). The answer is that atoms of one type of element (e.g., H) combine with the atoms of another element(s) (e.g., O) and form new types of matter (e.g., H_2O). These new types of matter are called chemical compounds (aka molecules), and the force that holds the atoms together is called a chemical bond. In summary, there are many different types of elements (atoms). Although some exist in their pure form, atoms of different elements often combine to make new types of matter called **compounds**.

Compound (aka <u>molecule</u> for Bio101): A substance (or type of matter) containing two or more elements (atoms) in a fixed ratio. In Bio101 we will use the term **<u>molecule</u>** synonymously with compound! (Technically speaking though, a molecule is a compound bonded together with covalent bonds.)

At this point you might be wondering the following: OK, so different atoms can combine to form molecules, but how do they do so? Furthermore, what determines which types of atoms will combine with atoms of other elements? The answer lies in the electrons! The # of electrons in an atom's outermost valence shell determines how atoms (elements) react with other atoms. Atoms form a chemical bond by sharing or transferring electrons. The making and breaking of chemical bonds is a chemical reaction (more on this below).

Chemical bond: An attraction between two atoms resulting from the sharing or transfer of electrons (e^-).
Chemical reactions: The making and breaking of chemical bonds

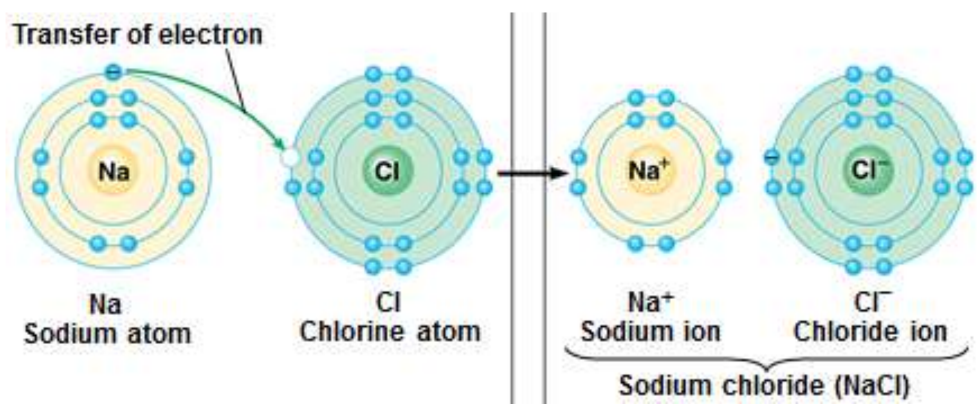
Chemical reactions happen because atoms "want" their outermost valence shell (orbital) to be full of electrons. The more accurate way to say this is that atoms are more stable when their outermost orbital is full of electrons. Thus, two atoms in close physical proximity might either share or transfer electrons among compatible atoms, when this happens the participant atoms remain in very tight proximity and are said to be **chemically bonded.**

There are two types of bonds that arise from the transfer or sharing of electrons between two atoms:
1) **Ionic bonds** (you should know about these, but we won't discuss them and you won't be tested on them), and;
2) **covalent bonds** (we will discuss and manipulate these regularly in Bio101)

Ionic Bonds: Definition and Example

Ionic Bond: A chemical bond in which outermost valence shells are filled through **transfer of an electron** (EX: NaCl).

In the following example of an ionic bond, note how the electron is transferred from the Na atom to the chlorine atom. As a result of the transfer, the two atoms are "happier" (more stable). In addition, they both have a slight electrical charge, and the charge is opposite. This opposite charge causes an attraction (perhaps you've heard the term "opposites attract"?) and holds the two atoms in close physical proximity. This is an ionic bond.



Ion: Atom or molecule with a net positive or negative charge due to loss or gain of 1 or more electrons (EX: Na^+, Cl^-).

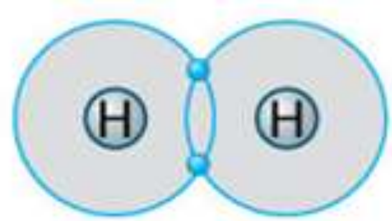
VIDEO: https://www.youtube.com/watch?v=CGA8sRwqIFg (0:00-6:04)
The first six minutes of this video provides some background of the material from parts I and II of this document, and it explores ionic bonds. For now, watch 0:00-6:04.
BEWARE! This video contains additional information, so be careful not to "over study" material for which you are not responsible.

Covalent Bonds: Definition and Examples

Covalent Bond: A chemical bond in which outermost valence shells are filled through sharing of electrons (EX H_2, O_2). Think of root of word "co-valent". Covalent bonds are stronger than ionic bonds.
Molecule: two or more atoms held together by covalent bonds.

Single covalent bond: a covalent bond in which one electron from each atom is shared to form the bond (Example: H_2).

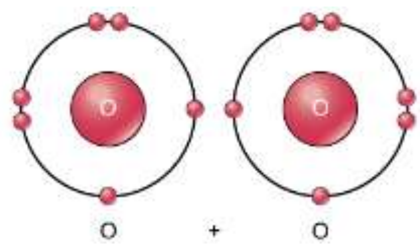
H_2 (hydrogen gas) is an example of a single covalent bond
In order to fully understand the example at right, first locate H (hydrogen) on the periodic table. Really. Go there now…! See it?! Right, good, that's it in the very upper left corner and its atomic number is 1. Thus, every H atom has 1 proton and one electron (for now, and usually, we will alter this statement in subsequent lectures).
Recall that the innermost valence shell of any atom can contain a maximum of two e^-. Thus, when two H atoms come into close proximity, they share 1 e^- each and thereby fill their outermost valence shell (which just happens to be their only valence shell).



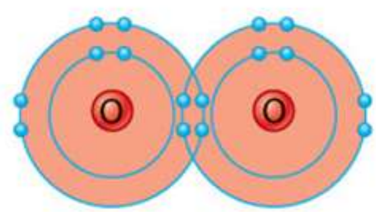
Two H atoms covalently bonded. Note that two electrons are being shared, and this sharing fills the outermost orbital of each atom. This is a single covalent bond (two electrons are being shared).

Double covalent bond – A covalent bond in which two electrons from each atom are shared (EX: O_2)

Let's turn our attention to O atoms, the constituents of O_2 ("molecular oxygen"). Find O on the periodic table and understand the electron distribution diagram at right. There are 8 total e^-, two occur in the inner orbital and six in the outer orbital (the author of the diagram at right chose to only illustrate the outer orbital).
With six electrons in the outer orbital, each O atom is two electrons short of having a full outer valence shell of eight electrons (this is referred to as a "stable octet", you'll be hearing this throughout your career). In order to achieve a stable octet (I told you so…), each atom must now share two of its own electrons for a total of four in the bond space (see lower image at right).
Now then, if the bond resulting from the sharing of two electrons is referred to as single covalent, what do you suppose chemists call the bond that forms from the sharing of four electrons? That's right, double covalent! We will discuss single and double covalent bonds FREQUENTLY in this ocurse. You should be very comfortable with this material. Practice drawing electron distribution models for O atoms and O2 molecules!



Two oxygen atoms, not yet bonded…such lonely electrons…



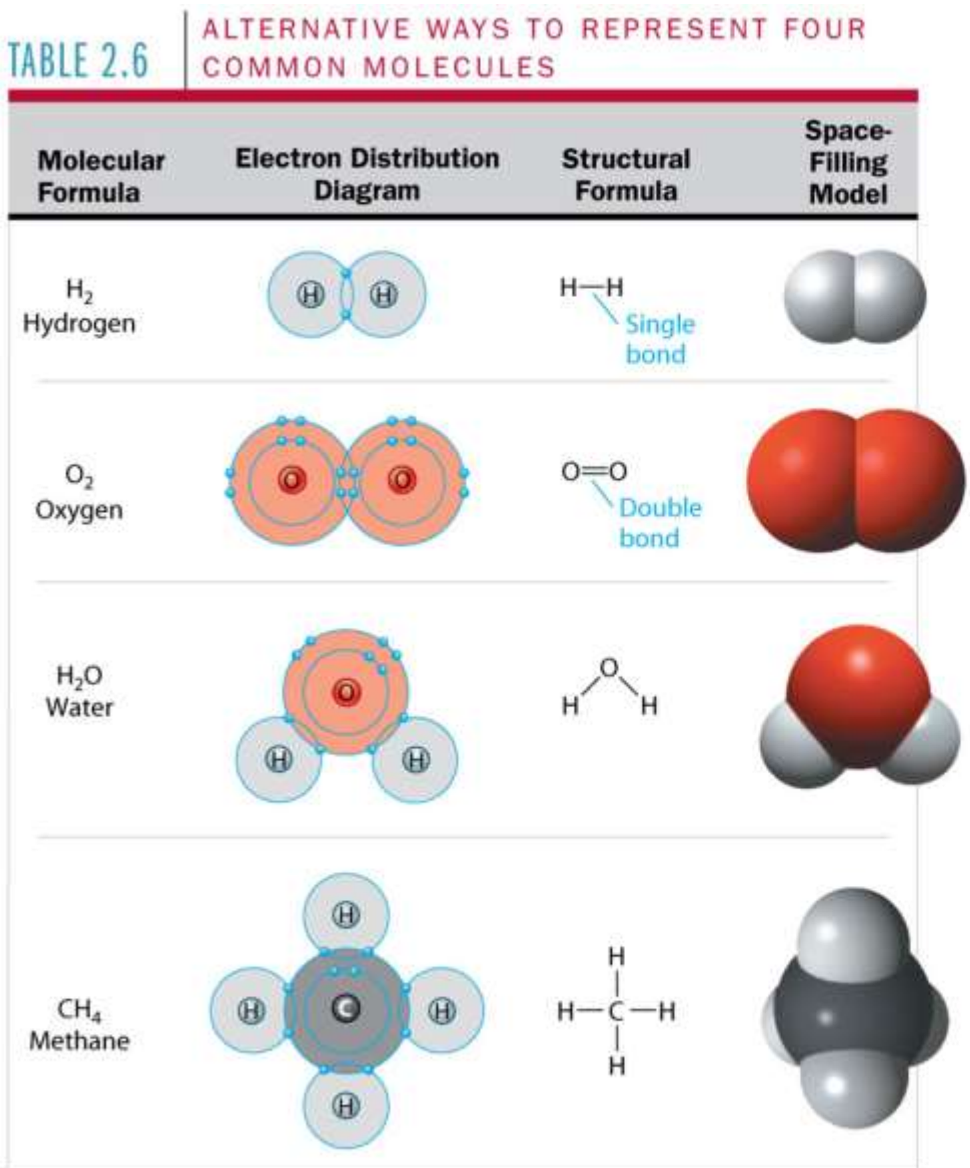
Two oxygen atoms, bonded covalently through the sharing of two electrons from each atom (four total shared electrons, can you explain why?). This is a double covalent bond.

VIDEO: https://www.youtube.com/watch?v=CGA8sRwqIFg
Same video as above for ionic bonds, now **watch 6:04-10:40.**
BEWARE! This video contains additional information, so be careful not to "over study" material for which you are not responsible.

Part IV: Symbols for representing and describing molecules

We will use three systems for writing and describing molecules in Bio101. These are:
Molecular Formula (e.g., H_2O, O_2, etc…)
Bohr model (aka, electron distribution diagram)
Structural Formula (aka, "ball-and-stick")
(We will make very limited use of space-filling models, but they are useful visualization. We'll use very simple and 2D space-filling models when we draw water molecules…more below!)

Examine the table below and familiarize yourself with these three ways to represent molecules. (Note especially the single line that represents a single covalent bond, and the "double line" that represents a double covalent bond).



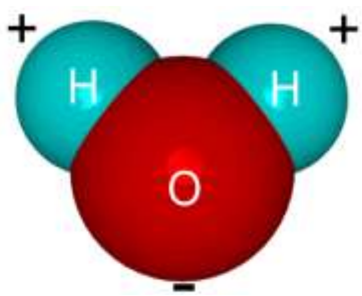
Part V: Water, a polar and "bent" molecule.

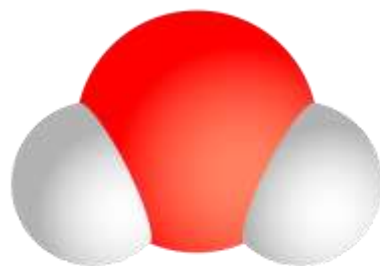
Examine the table on page 7, and look specifically at the electron distribution diagram and the structural formula for water. Notice that H_2O is "bent". We won't concern ourselves with why it is bent, but you need to be able to draw water as bent. Most people refer to it as looking like "Mickey Mouse" (see below).

In addition to being bent, water is also a polar molecule.
Nonpolar covalent bonds – electrons are "shared" evenly
Polar covalent bonds – covalent bonds in which one atom has a stronger affinity for the 'shared' electron(s), and the electron therefore spends more time near the atom with higher affinity. As a consequence there is a slight polarity (uneven charge) around the molecule. Often, this results in a polar molecule that has uneven charge around it (EX: H_2O)

In water the polarity is always as follows: a negative charge near the oxygen atom, at positive charges near the hydrogen atoms.

Throughout this course, you should be able to instantly recognize and draw water as a polar and bent molecule. For example:





Two models of water molecules that you should be able to write and recognize without hesitation!

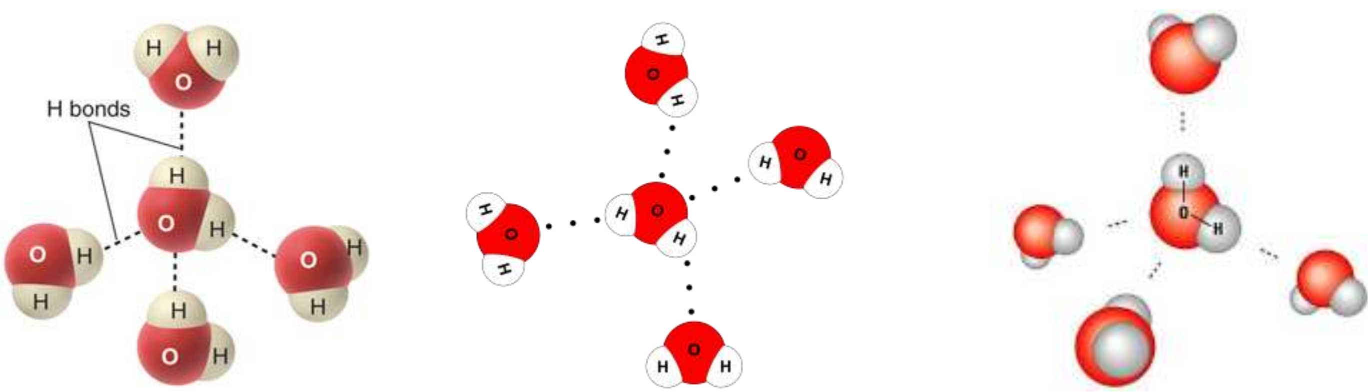
One consequence of water's polarity is that it makes water a very effective solvent. The charge imbalance of water molecules allows H_2O to disrupt the chemical bonds in other molecules. For this reason, water is often referred to as "the universal solvent". If you are rusty on your understanding of solvents and how they work, we will cover them in lab this semester. For now, make note of the following definitions (you will not be tested on them until after wee six, at which point you will see these in lab):

Solution: a liquid consisting of a uniform mixture of two or more substances
Solvent: the dissolving agent in a solution
Solute: the substance that is dissolved by the solvent

The nutrients and gasses in a plant, and in your body, are dissolved in water and plumbed throughout the body. We'll discuss this later in the course in great detail!

The polarity of H_2O molecules has an important effect on how water behaves as a substance (i.e., a mass of many molecules forming tangible matter…think of a glass of water, a lake, the ocean, or a raindrop). Specifically, when many H_2O molecules come into close proximity to each other, the positively charged H atoms are attracted to the negatively charged O atoms. This attraction is an example of a **hydrogen bond** (or, **H bond** for short)

Hydrogen bonds (H bonds): weak bond within or among molecules containing a charged hydrogen atom – THE key example in biology is water, but hydroxyl groups (-OH) are also important.



Three illustrations of H bonds among neighboring H_2O molecules. H bonds are universally represented as “dashed” or “dotted” lines. We’ll revisit h bonds in plants in at least two future lectures. This is also a fundamentally important concept of biology that any bio major should file away mentally and be ready to recall.

Part VI: Chemical reactions and chemical equations

Chemical reactions: The making and breaking of chemical bonds
Reactants: the starting atoms/molecules that are "used up" in a chemical reaction
Products: the atoms/molecules that are produced in a chemical reaction

Chemical equation: a symbolic equation representing a chemical reaction, in which the reactants are on one side of the equation and the products are on the other side. Between the reactants and products is an arrow, which represents the reaction itself.
(Note: chemical equations are usually written using atomic symbols and molecular formulas, but sometimes we use electron distribution diagrams or structural formulas).

Consider the example of oxygen above, on page 6, in which two O atoms bonded to form O_2. A much more succinct way to write this process, or chemical reaction, is with a chemical equation. So, instead of writing "which two O atoms bonded to form O_2", we simply write:

$$O + O \rightarrow O_2$$

The utility of chemical equations is even greater for more complex reactions. Take, for example, the reaction of photosynthesis. We'll spend three lectures discussing the importance of this reaction, in which plants take carbon dioxide and water and convert it into sugar (glucose) and molecular oxygen. Instead of writing the preceding sentence, we write photosynthesis as:

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

Balancing chemical equation – matter (atoms) is neither created nor destroyed during reactions, so make sure all atoms are accounted for on both sides of equation!! For example, a balanced chemical equation for photosynthesis is:

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

This document contains the fundamentals of chemistry that you will need to succeed in Bio101. It's not a large volume of material, but it is critical that you master the concepts in each of the sections herein. We'll be applying these tools frequently and for the duration of the semester!

GOOD NEWS…You Made It!

Now try the homework!

You really WILL use this knowledge in your biology career, whatever it is!