BZE W22 Lecture 1: Carbon & Functional Groups, Properties of Water, Polarity, Water as Solvent, pH

Source:
Reece J et al. *Campbell Biology (Canadian Edition)*. 3rd Ed. Pearson Canada

Use the textbook & your lecture notes to complete the tasks indicated in bold green lettering. Note that you are responsible for all the answers to these tasks.

Before starting, review The Chemical Context of Life – particularly the different types of bonds (covalent, etc.) Chapter 2.

A) Organic Molecules: ALL of Chapter 4

1. **Review what distinguishes living things from non-living things. You should list at least 6 factors.** Reegro
2. **Define metabolism.** All chemical reactions that occur in a living thing
3. **List the macromolecules that distinguish living things from non-living things on Earth & which are the foundations of metabolic activities w/i all organisms.**
   Lipids, carbs, proteins and nucleic acid
4. **List the elements that form most these macromolecules**: C, H, O, N, P and sometimes S

The overall % of these elements are uniform in most living organisms; this reflects the **common evolutionary origin of all life on Earth**. However, different species & individuals w/i species have variations in the types/quantities of organic molecules synthesized from these elements: this is one of the characteristics of **diversity among organisms**.

The building blocks of macromolecules themselves are **organic molecules**.

5. **Define organic.** Containing C and H and made by a living thing
6. **List the 2 elements that are the "backbone" of all organic molecules.** C and H

If we disregard water, nearly all the molecules of a cell & of an organism are carbon compounds.

If all organic molecules have the same backbone, how is it they do not have the same function?

7. **List the 2 factors that give different organic molecules their distinctive properties:**

A. arrangement of C-skeleton
B. functional group(s) attached

8. **Explain what is meant by a covalent bond.** Bond where electrons are shared equally H H
9. **What is the difference b/w a non-polar & a polar covalent bond** (see page 4 of this document)? when one atom is more electronegative than the other atom in a covalent bond, electrons are not shared as equally - this is a polar covalent bond.

10. **Carbon can form up to (#) ____ COVALENT bonds.**

C to C bonds are strong **covalent** bonds & are well suited to form a macromolecule. Carbon atoms form chains & rings & can generate large & complex molecules.
Single bonds b/w carbons allow flexibility (rotation) of the molecule. Double bonds b/w carbons provide more stability & strength to the molecule.

1) **Arrangement of the carbon skeleton:** carbon skeletons can vary in **length**, can be **branched** or **unbranched**, can contain **double bonds** or **not**, plus the position of these double bonds can vary, & some carbon skeletons can be arranged in **rings**.

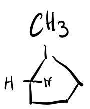
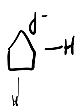
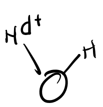
See Figure 4.5 Chapter 4

2) **Molecular components attached to carbon skeleton**: Certain **groups of atoms** are frequently attached to carbon skeletons in organic molecules. These groupings of atoms are called **functional groups**. These functional groups change the properties & therefore the functions of organic molecules.

See Figure 4.10 Chapter 4

11. Define hydrophobic. Non-ionic, non-polar and does not interact with water, does not form H-bonds with water and is not dissolved by water

- **Hydrocarbons** HC: formed by **covalent**, relatively **non-polar** bonds b/w **C** & **H** **with no other functional groups attached**.

Although hydrocarbons are not prevalent in most living organisms (petroleum is made up of *dead* organisms), many organic molecules have regions composed of only C & H. In these cases, the molecules are:

I. Generally **insoluble** in water, i.e., are not dissolved by water; they cluster together through **non-polar hydrophobic interactions**. Why are they insoluble? They *can* interact with water but, do so much more weakly than water molecules do with each other through hydrogen bonds. Therefore, **hydrocarbons are *excluded* from the hydrogen-bonded water molecules**;
II. Release a **large amount of energy when catabolized (broken-down)**; therefore, organic molecules such as triglycerides (fats), which are composed of large regions of hydrocarbons, store fuel which can be used to produce large amounts of adenosine triphosphate (ATP) in the mitochondria in both plants & animals (we will be seeing this in more detail when we cover Cellular Respiration).

12. Define cis & trans isomers & enantiomers. Cis, 2atoms are on the same side of bond, trans, 2 atoms are on opposite side of bond. Enantiomers

By replacing one of the hydrogens with one or more functional groups the characteristics of organic molecules can be altered. In other words, the addition of specific functional groups to a molecule underlies the specific FUNCTION(S) of that molecule (**form = function**). Most functional groups readily form associations such as **ionic** & **hydrogen bonds** with other molecules, **& polar & ionic functional groups readily associate with polar water molecules** & are thus **hydrophilic**.

13. Define hydrophilic. Polar, ionic

The most common functional groups are:
Note that the symbol R is used to designate the remainder of the molecule the functional groups is a part of.

- **Methyl group**: R-CH_3. When added to DNA or to the proteins associated with DNA it affects the expression of genes (i.e., impacts the transcription & translation of DNA). It also affects the shape & therefore the function of male & female steroid hormones.

- **Hydroxyl groups**: R-**OH** or **HO**-R. Hydroxyl groups are **polar** (**they DO NOT ionize**). **Sugars** owe their solubility in water to the presence of hydroxyl groups. Organic compounds containing hydroxyl groups are called **alcohols** (ethanol, methanol, etc.)

- **Carbonyl groups**: R-**C=O**$^{\delta -}$. Carbonyl groups, such as **aldehydes** & **ketones**, are **polar** (**they DO NOT ionize**). Aldehydes contain the **carbonyl carbon bonded to at least one hydrogen – i.e., the carbonyl group is found at one the end of a carbon skeleton. Ketones have the carbonyl carbon bonded to two other carbons – i.e., the carbonyl group is found w/i the carbon skeleton**. Simple **sugars** (**carbohydrates**) can be aldehydes or ketones & dissolve easily in H_2O.

- **Carboxyl groups**: R-**COOH**. This functional group is an important part of **amino acids** & **proteins**. **NOTE: in cells, this functional group is found in the ionized form COO^-**.

- **Amino groups**: R-NH_2. This functional group is also an important part of **amino acids** & **proteins**. As well, amino groups occur in several ring structures which are constituents of **DNA** & **RNA**. **NOTE: under cellular conditions this functional group is found in the ionized form NH_3^+.**

- **Phosphate groups:** R-PO_4H_2. Phosphate groups are constituents of **nucleotides** (such as **ATP**), **nucleic acids** (**DNA** & **RNA**) & **phospholipids**. **NOTE: in cells this functional group contributes a negative charge to the molecule of which it is part – if it's found inside a chain of Ps then the charge of the functional group is 1-, when it's at the end of a chain of Ps the charge of the functional group is 2-.**

- **Sulfhydryl groups**: R-**SH**. Sulfhydryl groups help **stabilize** the **internal tertiary structures** of certain **proteins**. NOTE: this functional group can be found w/i the R group of an amino acid – i.e., methionine, OR in the terminal region of the R group – i.e., cysteine. Either way, **it DOES NOT ionize**.

Most of the cell's organic compounds have 2 or more different functional groups attached to their carbon skeleton. **When it is known what kinds of functional groups are present in an organic compound then its chemical behavior can be predicted**.

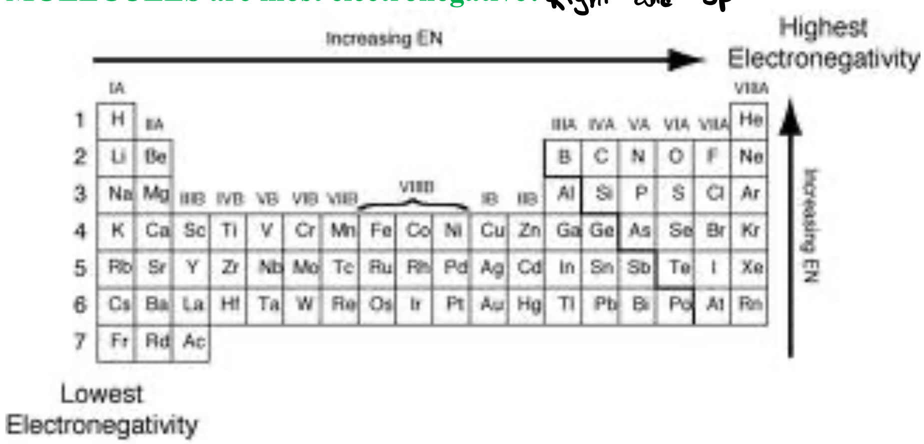
14. As a review exercise (for both biology & chemistry) answer the following questions in the textbook Chapter 4: # 2, 3, 4 & 7 page 69.

B) Water as Solvent

1. **Read Concept 3.2 Cohesion of Water Molecules, Moderation of Temperature by Water, & Floating of Ice on Liquid Water pages 48-51. I will not cover this in class, but <u>you are responsible for this material</u>.**

Electronegativity & Polarity

2. **Define the term <u>electronegativity</u>.** the potential to attract the shared electron in a covalent bond more than the other atom in the bond.
3. **Looking at the periodic table, how do you know which elements FOUND IN ORGANIC MOLECULES are most electronegative?** Right and up



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4. **List the atoms commonly found in organic molecules, placing them in descending order of electronegativity.** O > N > C ≈ H

What is the link b/w **electronegativity & polarity**?

CH
- A **NONPOLAR <u>COVALENT</u>** bond is a bond b/w 2 atoms that have similar electronegativities – the electrons are shared equally by both atoms.
- A **POLAR <u>COVALENT</u>** bond occurs b/w 2 atoms that do not have the same electronegativities. **This bond has 2 *dissimilar* ends** – 2 POLES. **One has a <u>PARTIAL</u> (+) charge (written as δ+) & the other a <u>PARTIAL</u> (–) charge (written as δ-)**.

OH

Important: a molecule with one or more polar covalent bonds can be **polar** while being **<u>electrically neutral</u>**. **<u>IMPORTANT: ONLY COVALENT BONDS CAN BE POLAR OR NON-POLAR</u>**

Water & polarity

5. **Where does the Earth's atmospheric O_2 come from?** water
6. **What is the name of the process that releases O_2 into the atmosphere?** photosythesis

7. **List <u>3 different groups of organisms</u> capable of carrying out this process.** Certain bacteria, all plants, certain protists

Oxygen is one of the most electronegative of all atoms found in organic molecules, while hydrogen is one of the weakest electronegative of all atoms.

In addition, **water is a polar** (non-organic) **molecule**. The hydrogen atoms & the oxygen atom are linked by polar covalent bonds. O attracts the shared electrons in H_2O much more strongly than the very weakly electronegative H, so the shared electrons are closer to the O than the H. This implies that O has a δ- charge, while each H has a δ+ charge. Important: **H_2O is NOT an electrically charged molecule**!

Hydrogen Bonding

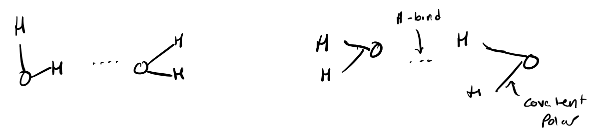
Water & Hydrogen Bonds
The fact that H_2O is a polar molecule is the basis of many of its important functions, one of which is to form **hydrogen bonds** with other molecules (including of course other water molecules) & DISSOLVE these other molecules.

8. **Define hydrogen bond.** Occurs b/w a H that is covalently bonded to an atom with a higher electronegativity such as O or N. That H has a δ+ charge and can be attracted to a different electronegative atom nearby
9. **HYDROGEN BONDS tend to form b/w:**

A. H and O
B. H and N

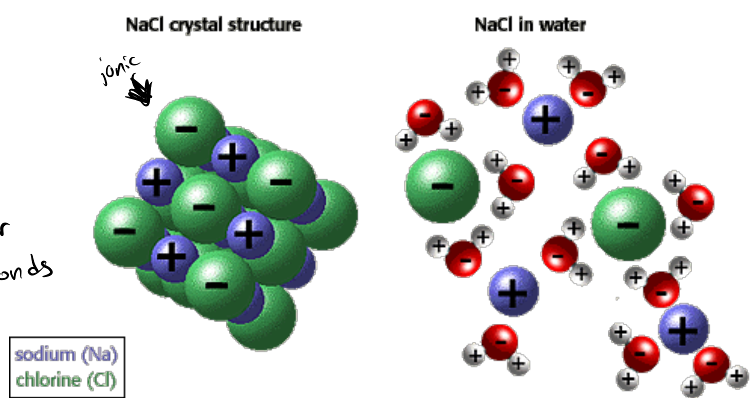
The atoms involved in the hydrogen bonding can be in 2 different parts of the same molecule or in 2 different molecules.

10. **Draw an example of a hydrogen bond b/w 2 water molecules.**



Here is an example of hydrogen bonding b/w a water molecule & a molecule of salt

ionic bonds dissolve in water because theyre weaker than water bonds



http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html

Hydrogen bonds are considered weak bonds, unlike covalent or ionic bonds. **Hydrogen bonds are easily formed & easily broken**. This is an important property, which will be demonstrated when we look at **DNA**, for e.g. **Although they are individually weak, collectively hydrogen bonds can be very strong when present in large numbers**.
B/c of all of this, **hydrogen bonds play a very critical role in the 3-D structure of large macromolecules such as proteins & DNA**.
Water as the universal solvent

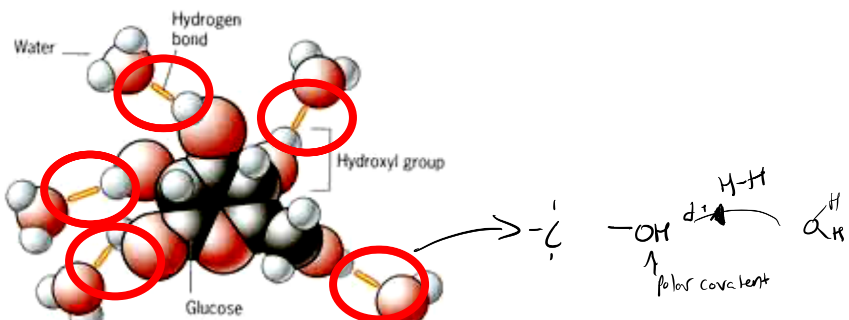
~70% of the human body's weight is water. Humans can survive weeks w/o food but only a few days w/o water. Most cells in the body are surrounded by water, & cells themselves are ~70-95% water (85% of each neuron in the brain is water, for e.g.). So, we are basically bags of aqueous solutions!

11. What is a solution? A liquid that is a homogeneous mix of 2 or > substances
12. Compare solvent to solute.
The **solvent** is the dissolving agent. The **solute** is substance being dissolved.

An **aqueous solution** is one in which water is the solvent. **Water is capable of dissolving substances that are polar or ionic b/c of its polarity**.

E.g., of a **polar** compound being dissolved:

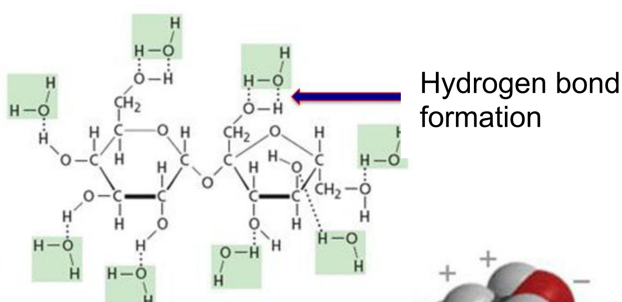
Sugars such as glucose (monomer) & sucrose (disaccharide) are polar.

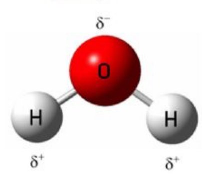


A molecule of glucose in water

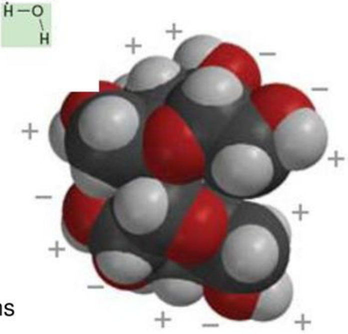
When sucrose macromolecules are mixed with water, the water molecules arrange themselves around the sucrose molecules according to opposite polar areas. **The attraction of the water molecules & their motion are stronger than the attraction b/w sucrose molecules. The sucrose molecules dissolve as they are separated from each other & mix into the water**.

A sucrose solution is a non-electrolyte.



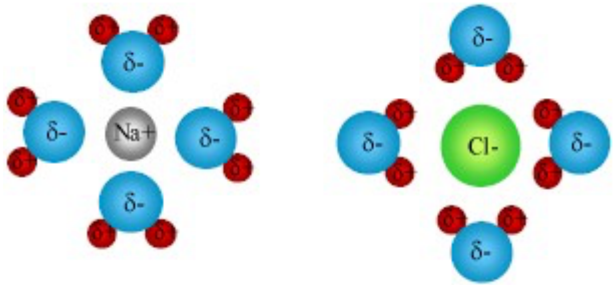


Partial charges shown on selected atoms



E.g., of an ionic compound being dissolved:

The δ+ charge of the H & the δ– charge of the O of each water molecule attract & surround **anions** (for e.g., Cl^-) & **cations** (for e.g., Na^+) respectively in a salt through a process called **hydration**.
The result is the b/d of NaCl - the solid is **dissolved**.



Water is the solvent inside all cells, in blood & in plant sap, for e.g., & it therefore dissolves a large variety of solutes necessary for life.

NOTE: some *very large* macromolecules, even though they are polar, can interact with water but *cannot be dissolved* by water. An e.g., of this is cotton, which is made up mostly of cellulose, a polar carbohydrate that cannot be dissolved by water (thus the use of cotton towels to dry surfaces!).

pH

13. What does the acronym "pH" stand for?

Remember that the pH of a solution is defined as the negative logarithm (*base 10*) of H^+ (hydrogen ion) concentrations - e.g., a solution of pH7 has a concentration of H^+ of 10^{-7} M; a solution of pH6 has a H^+ concentration of 10^{-6} M. **Therefore, a change in pH is NOT the addition or removal of one (1) H^+ ion!**

In an aqueous solution *most* water molecules are intact. However, some of the water molecules can break apart & dissociate into H^+ & OH^- (hydroxide ion).

14. What is this process called?

It is a reversible reaction: $H_2O \leftrightarrow H^+ + OH^-$

H^+ & OH^- are very reactive & changes in their concentration can affect other molecules, macromolecules, the cell's function & the organism's function.
A solution in which the concentration of H^+ & OH^- are equal is a neutral solution. Pure water is a neutral solution. However, adding certain solutes called acids & bases can affect the balance of H^+ & OH^- ions.

15. What is an acid? A substance that __________ H^+ concentration in solution.

E.g.: HCl in the stomach dissociates into H^+ & Cl^-, making the stomach environment very acidic (pH2).

16. What is a base? A substance that __________ H^+ concentration in solution.

E.g.: ammonia $NH_3 + H^+ \leftrightarrow NH_4^+$
Other bases decrease the concentration of H^+ by donating OH^- to the solution; the OH^- combines with H^+ to form water.

The **pH scale** is used to describe the concentration of H^+ & OH^- in a solution.

- A low pH means there is a high concentration of H^+ & a low concentration of OH^- & the solution is acidic.
- A high pH means there is a low concentration of H^+ & a high concentration of OH^- & the solution is basic.

17. Answer the following questions in the textbook: # 1, 3, 4, 6, 7 & 8.