BIO 181 Laboratory Exercise

Name:______________________________

BIOMOLECULES

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1 Introduction

Imagine shrinking so small that you could see molecules as if they were ordinary objects (assuming that's possible). Now imagine finding yourself in a living cell. What would you see? Would you be able to tell, just from the cell's contents, what sort of organism you'd invaded?

Surprisingly, the answer is essentially "no," or at least it wouldn't be easy. All the nearly 1.5 million species we've identified so far are based on the same chemistry. They all have about the same atoms and molecules in about the same proportions. That's not to say all are chemically identical; for example, if you saw lots of chlorophyll you could guess you were in a plant. But the great majority of chemicals and chemical processes occurring within a human being are very similar to those in saguaro cacti, pine martens, syphilis bacteria, mackerels and everything else.

So, what would you see? Water molecules more than anything else; about 70% of all life is water. Next most abundant would be enormous molecules (relative to water) called ***macromolecules*** of various types, including ***polysaccharides*** or complex sugars, along with giant blobs called ***proteins***. ***Nucleic acids*** like DNA and RNA would also be fairly abundant. In addition to these huge molecules, you could find a number of smaller ones, including ***amino acids***, ***nucleotides***, ***monosaccharides*** and larger ***disaccharides***. In certain areas you'd find clumps of molecules of all different shapes and sizes but sharing the inability to dissolve well in water. These are the ***lipids***. Finally, you would see a number of tiny ions, like "charged atoms," including sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), chloride (Cl^-) and perhaps magnesium (Mg^{2+}). All these things—water, macromolecules, small molecules, lipids and ions—would be mixed together into a giant soup. Sometimes you might see patterns in this jumble, like a great sheet of phospholipids in a cells membrane, or you might notice that about 10 times more Na^+ exists outside the cell compared to inside, but mostly the jumble would be apparent chaos. Here we explore the properties of the ingredients of this chaotic soup and learn their molecular structures.

2 Properties of Atoms

An ***atom*** is the smallest electrically neutral unit of an ***element*** that possesses that element's chemical properties. An element is a substance (powder, crystal, liquid, etc.) that cannot be broken down into another substance. So, think of an element as some sort of stuff that you can see and an atom as the smallest particle of that stuff, so small that your eye cannot detect it. Atoms can be further broken down into smaller particles, including protons (charge = +1), neutrons (charge = 0) and electrons (charge = −1), but these particles no longer have the chemical properties of any element; in fact, when we break an atom down into its constituent atomic particles we leave chemistry and enter the world of physics. So far over 100 elements have been discovered, but biologists need to study only the properties of a few since the vast majority are not abundant in living things.

Refer to a periodic table to complete the procedures below. You may find a periodic table in your text, on the wall of the lab or in the library in any general chemistry book. Also, there are a number of excellent periodic tables on the web. (See the BIO 181 course website maintained by Dr. Nagy for a link to one at Los Alamos National Laboratory.)

Each entry in the periodic table contains at least three pieces of information: the elemental symbol (usually the first letter or two in the element's name, either in Latin or Greek); the element's ***atomic number***, or number of protons in its nucleus; and the element's ***atomic mass***.

Most of the smaller atoms contain equal numbers of protons, electrons and neutrons. For example, most carbon atoms have exactly 6 protons, 6 electrons and 6 neutrons. (Hydrogen is an exception; most hydrogen atoms contain a single proton in the nucleus, one electron and no neutrons at all.) Since protons and neutrons are nearly the same mass (each is 1 atomic mass unit, or amu), the atomic mass of most atoms is twice the atomic number. So, most carbon atoms weigh 12 amu (the weight of 6 protons plus 6 neutrons).

However, in Nature you will find some carbon atoms that don't weigh 12 amu, but a little more. Some weigh 13 and others 14 amu. Each of these different types of carbon have the same number of protons (otherwise they wouldn't be carbon) but have varying numbers of neutrons. Atoms with different weights but the same atomic number are called isotopes of a given element. So, there are three common isotopes of carbon: carbon 12 (6 neutrons); carbon 13 (7 neutrons) and carbon 14 (8 neutrons). To show the isotope when we write the elemental symbol, we write the atomic mass as a superscript to the left of the symbol. So ^{12}C refers to carbon with 6 neutrons and ^{14}C means carbon with 8 neutrons.

The atomic mass, as found on a periodic table, is an average of all isotopes of an element weighted by their natural abundances. For example, about 98.93% of all carbon atoms in nature are ^{12}C and 1.07% are ^{13}C. Only a tiny, negligible (to this level of precision) fraction is ^{14}C. Therefore, the atomic mass of C is

$$\frac{98.93(12) + 1.07(13)}{100} = 12.011 \text{ amu.} \tag{1}$$

Generalizing this formula for atomic mass of any element, we let f_i be the natural abundance of the element's ith isotope and x_i be its mass and obtain

$$\text{Atomic mass } = \frac{f_1 x_1 + f_2 x_2 + \ldots + f_n x_n}{f_1 + f_2 + \ldots + f_n}, \tag{2}$$

assuming n isotopes. In example (1) above, $f_1 = 98.93$, $f_2 = 1.07$, $x_1 = 12$, $x_2 = 13$ and $n = 2$.

By definition an atom is electrically neutral, so it must have equal numbers of protons and electrons. However, at times atoms can either gain or lose electrons, in which case we call them ions. For example, in aqueous solution Na tends to lose an electron and therefore ends up with a charge of $+1$. Chlorine in aqueous solution tends to pick up an electron and ends up with a -1 charge. When we write the symbol for an ion we write the charge as a superscript to the right of the elemental symbol. Therefore, Na^+ and Cl^- represent the sodium and chloride ions, respectively.

Table 1 lists the major elements of living things. Consult a periodic table and fill in the symbols, atomic numbers and atomic masses. Table 2 lists a series of strong (covalent or ionic) bonds commonly found in the compounds out of which life is made. Fill in the type of bond, either covalent or ionic, that you would predict to exist between the elements listed. (HINT: Non-metals bound together tend to form covalent bonds; metals bonded to nonmetals tend to form ionic bonds. In the biologically important compounds in this lab, H acts as a nonmetal.)

Table 1: Properties of atoms commonly found in organisms.

Element	**Symbol**	**Atomic Number**	**Atomic Mass**
Carbon			
Hydrogen			
Nitrogen			
Oxygen			
Phosphorus			
Sulfer			
Calcium			
Sodium			
Potassium			
Magnesium			
Chlorine			

Table 2: Typical types of bonds formed by the elements commonly found in living things.

Bond	**Type (Covalent or Ionic)**
C—C	
C—H	
C—N	
Na—Cl	
Ca—Cl	
N—O	
O—H	
N—H	
P—O	

3 Molecular Structures of Biomolecules

In the following procedures you will draw representations of the building blocks of biological macromolecules. Ultimately you want to be able to identify each type of molecule in either a model or written representation. It may help, therefore, to build models of these molecules yourself. Molecular model kits are available in the tutor center.

3.1 Warm-up

In the space below, draw the structural formulas for water (H_2O) and carbon dioxide (CO_2). In your drawings, show the proper angle of the covalent bonds. (The structural formula is a drawing of the spatial arrangement of atoms in a molecule where lines represent a single covalent bond. For example, a carbon-hydrogen bond is drawn like this: C—H.)

Drawings of water and carbon dioxide:

3.2 Carbohydrates

Carbohydrates include all sugars, both complex and simple. They share the general formula $[CH_2O]_n$, meaning that there is (about) one water molecule ("hydrate") for every carbon ("carbo"). For example, glucose has the formula $C_6H_{12}O_6$, making, in this case, $n = 6$. In more complex sugars, this formula is only approximated. For example, sucrose (table sugar) has the formula $C_{12}H_{22}O_{11}$, but is still a carbohydrate.

1. In your text or on the internet, look up the ring structure of both α-glucose and β-glucose. (Glucose of both types have the same molecular formula but different structural formulas; therefore, they are isomers of glucose. Note: the symbols "α" and "β" are the lower-case, Greek letters "alpha" and "beta," respectively.) Look carefully at the locations of the –H and –OH groups on the two molecules. In the space below, draw these two isomers of glucose, and number all carbons using the standard numbering scheme (see the text).

α-glucose β-glucose

2. Glucose is a ***monosaccharide***; that is, it can exist as a single unit, or combine with other glucose units into long chains of sugars called ***polysaccharides***. Two common polysaccharides are ***starch*** and ***cellulose***. In the space below, draw a section of starch exactly 4 monomers long. Be sure to connect the glucose monomers correctly.

3. Consult your text and contrast the structural and physical characteristics of starch, glycogen and cellulose by filling in the table below:

Property	**Starch**	**Glycogen**	**Cellulose**
Bond connecting monomers (α or β glycosidic)			
Produced by. . . ? (Plants, animals or both?)			
Molecular properties (Branched, unbranched or both?)			
Functional characteristics (Used for what purpose?)			

3.3 Lipids

Lipids are defined to be any organic compounds that do not dissolve in polar solvents but will dissolve in nonpolar solvents. They are by far the most diverse type of organic compounds, including triglycerides, cholesterol and its relatives, and waxes among many others.

1. Consult your book for the general structure of a fatty acid. In the space below, draw fatty acids with molecular formulas $C_5H_{10}O_2$ and $C_5H_8O_2$. HINT: the second one is ***unsaturated***. If you look up the meaning of that term in the text, you should have no trouble determining its structure.

$C_5H_{10}O_2$ $C_5H_8O_2$

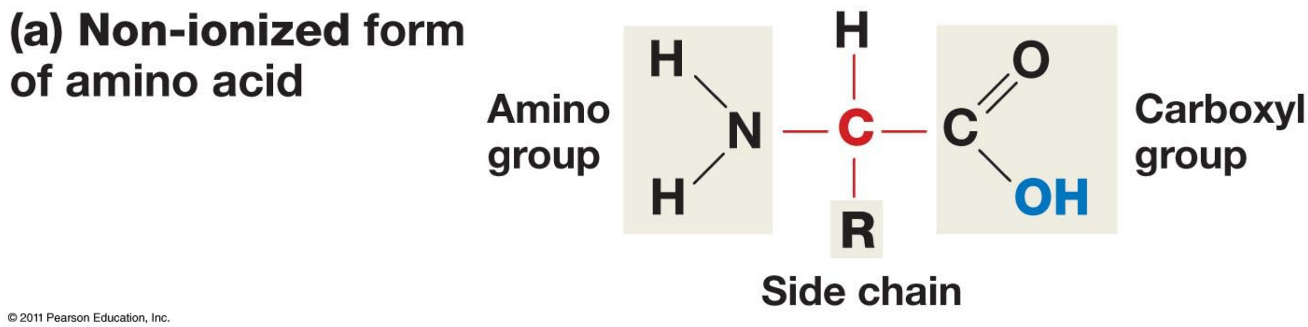

Figure 1: General structure of an amino acid in crystal (non-ionized) form. The molecule takes on the ionized form in aqueous solution (not shown; see text). All amino acids have amino and carboxyl (=acid) groups. The R stands for the variable side chain.

2. When triglycerides are made by cells, the carboxyl groups on the fatty acids react with the 3 hydroxyl groups on a glycerol molecule to form an ester linkage. This reaction is an example of dehydration synthesis (see your text). In the space below, draw a triglyceride (glycerol + 3 fatty acids with formula $C_5H_{10}O_2$) made in this way.

3. Compare and contrast (in words and/or drawings) triglycerides like the one you drew in the previous question with phospholipids found in living membranes.

3.4 Proteins and polypeptides

Polypeptides are polymers of amino acid monomers, and proteins are polypeptides long enough to fold into blobs ($>$ 80-ish amino acids). The amino acid monomers all have the same backbone structure of a central carbon with 3 constant groups attached—hydrogen, carboxyl (acid), and amino groups. A fourth group, often denoted R, is variable (Figure 1).

1. Using your textbook as a guide, in the space below draw the structural formulas for the amino acids glutamine and valine.

Glutamine Valine

2. Polypeptides are chains of amino acids connected together with peptide bonds. Using your textbook as a guide, draw the amino acids serine and threonine bonded together with a peptide bond.

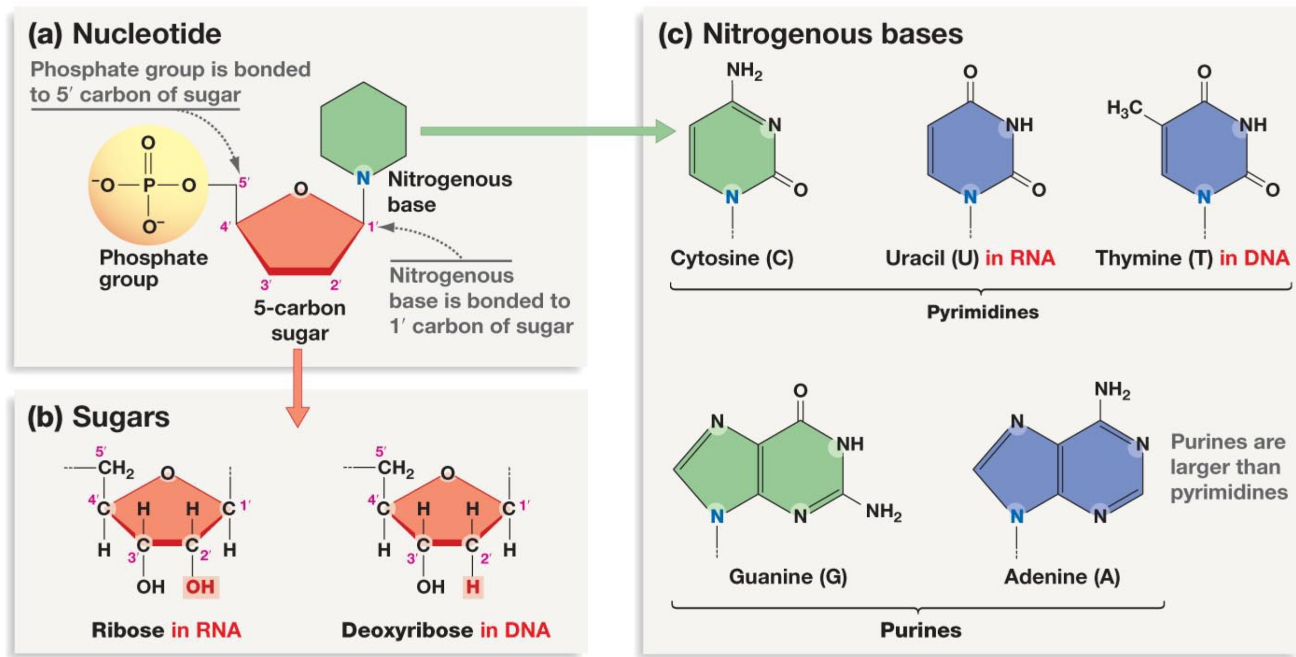

Figure 2: General structure of a nucleotide. The base is always attached to carbon 1′, and the phosphate always to carbon 5′.

3.5 Nucleic acids

Nucleic acids, DNA and RNA, are polymers of nucleotide monomers. A nucleotide consists of 3 basic units: a 5 carbon sugar (either ribose or deoxyribose), a phosphate group and either a purine or pyrimidine base (Figure 2).

1. Draw the structural formulas of adenine and thymine bonded together with hydrogen bonds as they would appear in DNA. Draw covalent bonds as solid lines and hydrogen bonds as dotted lines.

2. Draw the structural formulas of cytosine and guanine bonded together with hydrogen bonds as they would appear in DNA. Draw covalent bonds as solid lines and hydrogen bonds as dotted lines.

3. Which of these two base-pair bonds would you predict is stronger: adenine–thymine or cytosine–guanine? Explain your reasoning.

4 Exercises

1. For each of the notations in the table below, indicate how many protons, neutrons and electrons are represented:

Symbol	# Protons	# Neutrons	# Electrons
^{14}C			
^{3}H			
^{238}U			
$^{23}Na^{+}$			
$^{40}Ca^{2+}$			
$^{25}Mg^{2+}$			
$^{37}Cl^{-}$			

2. Use the following table to calculate the molecular weight of glucose ($C_6H_{12}O_6$). (HINT: you have atomic mass data from table 1.)

Element	# Atoms		Atomic mass		Molecular wt.
C		$\times$		$=$	
H	12	$\times$	1.00794	$=$	12. 095
O		$\times$		$=$	
Total	XXXXX		XXXXX	$=$	

3. What proportion of the mass of glucose is accounted for by oxygen? Show your work.

4. Calculate the molecular weight of palmitic (hexadecanoic) acid (a fatty acid with formula $C_{16}H_{32}O_2$). Show your work.

5. Calculate the molecular weight of lysine. (Youll find the structure in the text.) Show your work.

6. Classify each of the following molecules (HINT: there are 2 saturated fatty acids, 1 unsaturated fatty acid, an amino acid and a carbohydrate): $C_6H_{12}O_2$, $C_{18}H_{28}O_{16}$, $C_7H_{10}O_2$, $C_5H_{10}O_2$, $C_6H_{15}O_2N_4$. How many C=C double bonds does the unsaturated fatty acid in this list have?

7. The three most common isotopes of potassium are ^{39}K, ^{40}K and ^{41}K. Their natural abundances are 93.2581%, 0.0117% and 6.7302%, respectively. Use these data and the formula for a weighted average (equation 1) to calculate potassium's atomic mass. Show all calculations below. Compare your result to the value on a periodic table. Are they the same?

8. How many gallons of water would be produced by the dehydration synthesis of 3 moles of lysozyme, a protein with 129 amino acids? HINT: Do it step-by-step:
   (a) Calculate the moles of water produced;
   (b) Convert to kilograms using molecular mass of water;
   (c) Convert to liters (1 ml = 0.99656 grams of water at room temperature);
   (d) Finally, convert to gallons (1 L = 0.2642 gal).

9. BONUS: Approximately how many carbon atoms are in your body? (NOTE: you'll have to find or figure out the percentage of your mass due to carbon.)