Biochemistry and Biological Molecules

For some of you this will be a struggle. Let’s try to get through this part together!

1. **Some of the basics**
   a. Atomic Structure

**Atomic Structure**

<table>
<thead>
<tr>
<th>Subatomic Particle</th>
<th>Charge</th>
<th>Mass</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>Positive</td>
<td>Has mass</td>
<td>Nucleus</td>
</tr>
<tr>
<td>Neutrons</td>
<td>Neutral</td>
<td>Has mass</td>
<td>Nucleus</td>
</tr>
<tr>
<td>Electrons</td>
<td>Negative</td>
<td>Virtually no mass</td>
<td>Orbits around the nucleus</td>
</tr>
</tbody>
</table>

Atomic Number = Number of protons in the nucleus
Atomic Mass = Number of protons plus neutrons in the nucleus

Question: How do you calculate protons, neutrons and electrons?

b. Periodic Trends.
A periodic table looks like this:
Atoms have a tendency to react in certain ways:

- Increasing ionization energy
- Decreasing atomic radius
- Increasing nonmetallic character and electronegativity
- Decreasing metallic character

---

**Legend - click to find out more...**

- **H - gas**: Non-Metals
- **Li - solid**: Transition Metals
- **Br - liquid**: Rare Earth Metals
- **Tc - synthetic**: Halogens
- **Alkali Metals**
- **Alkali Earth Metals**
- **Other Metals**
- **Inert Elements**

---

Most metallic element
c. Isotopes:
Isotopes are naturally occurring substances which have more or less neutrons than a regular element of the substance. Carbon is a great example of this:

The atomic notation for these molecules look like this:

<table>
<thead>
<tr>
<th>Carbon 12</th>
<th>Carbon 13</th>
<th>Carbon 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 protons</td>
<td>6 protons</td>
<td>6 protons</td>
</tr>
<tr>
<td>6 neutrons</td>
<td>7 neutrons</td>
<td>8 neutrons</td>
</tr>
</tbody>
</table>

![Diagram of Carbon isotopes]

**FIGURE 2.3** These three carbon isotopes all have the same number of protons and thus the same atomic number, 6. Their atomic masses differ, however, because they have slightly different numbers of neutrons. The atomic mass of any element is the average of the weighted sum of the atomic masses of its various isotopes. One isotope of an element—for example, carbon-12—is far more abundant than the others because natural processes favor that particular isotope.

d. Electrons and the Bohr model

**Energy levels** - represent the orbital pathways of the electrons, these levels may be compared to balls that fit inside each other.

**Electron** - negatively charged particle which orbits the nucleus. In normal, neutral atoms, the number of electrons (e-) is equal to the number of protons.

- if the atom is not neutral/stable it will **donate/accept** or **share** e- a stable compound
- to be stable the:
  - inner most orbital needs 2e-
  - and the outermost orbital needs 8e-
  - (with the exception of Hydrogen and Helium, which only need 2e-)

→ **the Octet Rule**
Let's do some for practice:

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen</th>
<th>Carbon</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>Oxygen 2-</td>
<td>Floruine 1-</td>
<td></td>
</tr>
</tbody>
</table>

e. Molecules and Compounds

<table>
<thead>
<tr>
<th>Property</th>
<th>Molecular</th>
<th>Ionic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecules involved</strong></td>
<td>Two nonmetals</td>
<td>A nonmetal and a metal</td>
</tr>
<tr>
<td><strong>Electrons Transferred or shared</strong></td>
<td>Shared</td>
<td>Transferred in proportion to balance charges</td>
</tr>
<tr>
<td><strong>Crystal Shape</strong></td>
<td>Don’t form lattice structure because they are not charged molecules.</td>
<td>Form lattice structure because they are charged</td>
</tr>
<tr>
<td><strong>Melting Point</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Conductivity</strong></td>
<td>Doesn’t</td>
<td>Does</td>
</tr>
</tbody>
</table>
In covalent bonding there can sometimes be more than one pair of electrons shared. This results in double, or triple bonds, which look like this

<table>
<thead>
<tr>
<th>Oxygen gas</th>
<th>Nitrogen Gas</th>
</tr>
</thead>
</table>

**Question:** Which gases are always seen in 2 format if they are on their own? HOFBrINCl???

**f. Different ways of representing models:**

<table>
<thead>
<tr>
<th>Electron Model</th>
<th>Structural Formula</th>
<th>Molecular Formula</th>
<th>Ball and Stick</th>
<th>Space filling</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Electron Model" /></td>
<td>H-O-H</td>
<td>H_2O</td>
<td><img src="image2.png" alt="Ball and Stick" /></td>
<td><img src="image3.png" alt="Space filling" /></td>
</tr>
</tbody>
</table>

**g. Polarity:**
Sometimes when covalent bonding occurs, there is unequal sharing of electrons between the atoms. This causes partial charges to occur on the atom. Water is a great example of this:

**h. Properties of water**
i. Water has a high heat capacity:
ii. Water has high heat of vaporization
   it takes 540 calories of heat energy to move 1 g of water into vapour
iii. Water is a solvent
    All hydrophilic molecules dissolve in water
iv. Water molecules are cohesive and adhesive

\[ \text{H} - \text{O} - \text{H} \]

v. Water has a high surface tension
vi. Water has a higher density at a liquid than a solid (ice)

2. **Acid Base Chemistry**:
   a. Most substances can be classified into acid, base or neutral

| Acidic solutions produce high concentrations of H+ ions |
| Basic Solutions produce low concentrations of H+ ions |

The pH scale is a measurement of how acidic or basic a substance is. A pH of 7 represents a neutral solution where H+ ions and OH- ions are in balance. As you move from 7 to 0 on the pH scale, each movement represents ten times the H+ ions of the previous one. The same can be said for OH ions as you move from 7 to 14 on the pH scale.

**Acids:**

<table>
<thead>
<tr>
<th>Formula</th>
<th>Chemical Name</th>
<th>Formula in solution</th>
<th>Name of the Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>Hydrogen Fluoride</td>
<td>HF\textsuperscript{(aq)}</td>
<td>Hydrofluoric Acid</td>
</tr>
<tr>
<td>Formula</td>
<td>Chemical Name</td>
<td>Common Name</td>
<td>Example of Use</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------</td>
<td>-----------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrogen Chloride</td>
<td>HCl (aq)</td>
<td>Hydrochloric Acid</td>
</tr>
<tr>
<td>HI</td>
<td>Hydrogen Iodide</td>
<td>HI (aq)</td>
<td>Hydroiodic Acid</td>
</tr>
<tr>
<td>HClO₄</td>
<td>Hydrogen Perchlorate</td>
<td>HClO₄ (aq)</td>
<td>Perchloric Acid</td>
</tr>
</tbody>
</table>

### Bases:

<table>
<thead>
<tr>
<th>Formula</th>
<th>Chemical Name</th>
<th>Common Name</th>
<th>Example of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH</td>
<td>Sodium Hydroxide</td>
<td>Caustic Soda</td>
<td>Oven Cleaner</td>
</tr>
<tr>
<td>Mg(OH)₂</td>
<td>Magnesium Hydroxide</td>
<td>Milk of Magnesia</td>
<td>Antacids</td>
</tr>
</tbody>
</table>

Which of the following results when a base is added to a solution with a pH of 7?

**Hydrogen ion concentration in the solution**

<table>
<thead>
<tr>
<th>A. increases</th>
<th>B. increases</th>
<th>C. decreases</th>
<th>D. decreases</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH of the solution</td>
<td>increases</td>
<td>decreases</td>
<td>increases</td>
</tr>
</tbody>
</table>

b. Buffers

A chemical or a combination of chemicals that keep the pH within normal limits. This means they can take up excess H⁺ or OH⁻ ions, depending on what is in excess.

In animals pH must be maintained in body fluids or there can be serious health consequences. Our blood should be 7.4 on the pH scale. If it moves even .2 on the scale there are serious health consequences.
For pH stability we have built in buffers in our blood which help us maintain pH. Carbonic acid is a weak acid which can dissociate looking like this:

\[ \text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \]

When hydrogen ions are added to blood, this reaction occurs:
\[ \text{HCO}_3^- + \text{H}^+ \rightarrow \text{H}_2\text{CO}_3 \]

When excess hydroxide ions are added to blood, this reaction occurs:
\[ \text{OH}^- + \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}_2\text{O} \]

### 3. Organic and Inorganic Compounds:

<table>
<thead>
<tr>
<th>Organic</th>
<th>Refer to almost all carbon containing compounds that are naturally occurring or man made. Contain carbon and hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic</td>
<td>Do no contain carbon EXCEPT: CO\textsubscript{2} CO and all ionic carbonates. Example salts are inorganic NaCl</td>
</tr>
<tr>
<td>Functional group</td>
<td>Particular cluster of atoms that always behaves in a certain way. Example –COOH</td>
</tr>
<tr>
<td>Monomer</td>
<td>A simple organic molecule that exits individually</td>
</tr>
<tr>
<td>Polymer</td>
<td>Two or monomers put together Carbohydrate( \rightarrow ) Monosaccharide Protein ( \rightarrow ) Amino Acid Nucleic Acid ( \rightarrow ) Nucleotide</td>
</tr>
</tbody>
</table>

### a. Synthesis Reactions: (Dehydration Synthesis)

When you bring two organic molecules together to make a polymer, Dehydration Synthesis occurs, which is where water is taken out of the two monomers so they can be joined together.

\[ \text{H}-\text{A}-\text{OH} + \text{H}-\text{B}-\text{OH} \rightarrow \text{H}-\text{A}-\text{B}-\text{OH} + \text{HOH} \]

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \]

### b. Hydrolysis Reaction
This is the opposite of a dehydration synthesis, where water is added to take apart a complex molecule.

(b) Hydrolysis

4. Carbohydrates

Uses:
1. Quick energy and short term storage
2. Structural support in plants
3. on cell surfaces which are involved in cell to cell recognition

With the empirical formula of \( C_nH_{2n}O_n \)

a. Monosaccharides:
Mono meaning one- these are your simple sugars
   - Pentose- 5 carbons
   - Hexose- 6 carbons (glucose is a hexose, which is in blood)

b. disaccharides:
contain two monosaccharides that have joined during a dehydration reaction.
When Glucose and Fructose join they make Sucrose, which is what we use to sweeten our food.

Another disaccharide is lactose, which is glucose and galactose put together.

**c. Polysaccharides**

Starch, Glycogen, and Cellulose are the two main polysaccharides that contain glucose monomers.

Starch is composed of straight chain of glucose molecules. Starch is a storage form of glucose in plants.

Glycogen is a highly branched polymer of glucose. Glycogen is the storage form of glucose in animals.

Cellulose is found in plant cell walls and this accounts for their tough and rigid nature. Human digestive system can’t digest cellulose, so it passes through the intestines undigested. Other names for the cellulose in plant foods are "fiber" or "roughage."
Dietary fiber is important to health and for the prevention of such things as colon cancer.

\[ n \text{ glucose} \rightleftharpoons \text{starch} + (n - 1)\text{H}_2\text{O} \]

**synthesis**

**hydrolysis**

<table>
<thead>
<tr>
<th>Starch Structure</th>
<th>Glycogen structure – more branching!</th>
</tr>
</thead>
</table>

Cellulose structure:

- **W**: Glucose
- **X**: Maltose
- **Y**: Part of Starch or Glycogen
- **Z**: Cellulose
5. Lipids (Fats and Oils)
Lipids contain more energy per gram than other biological molecules. Fats come from an animal origin and oils come from a plant origin. Fats and Oils occur when one glycerol molecule reacts with three fatty acid molecules. This is why they are sometimes called Triglycerides.

a. Saturated vs. Unsaturated
A fatty acid is a hydrocarbon chain that ends with the acidic group – COOH.
If a fatty acid is saturated, it has no double bonds between carbon atoms. A unsaturated fatty acid contains double bonds between carbon atoms. Saturated fats are usually solid at room temperature and unsaturated fats are usually liquids at room temperature.
b. Phospholipids
Phospholipids contain phosphate! They are constructed just like fats, except instead of a their fatty acid they have a polar phosphate group. This phosphate group contains both nitrogen and phosphate.

Phospholipids are a molecule which makes up our cellular membrane. Phospholipids are amphiphatic, both hydrophobic and hydrophilic. They will spontaneously form a bilayer in which hydrophilic heads and hydrophobic tail line up.

Lipid bilayer membranes are permeable to oxygen, to lipids, and to small uncharged molecules, and water;

Phospholipid bilayer

c. Steroids
Contain a backbone of four fused carbon rings. Cholesterol is an important steroid which is a precursor to other steroids such as testosterone and estrogen.

Too much cholesterol and saturated fats can clog arteries in your circulatory system.

6. Proteins
Proteins are polymers with amino acid monomers.

Structural and enzymatic function
- composed of C, H, O, N, and sometimes P and S
- are associated with every structure in the cell and are involved in almost every cellular activity
- predominant kind of molecule found in cell
- ~50% of the dry weight of living matter is protein
- generally quite large
- despite their diverse function, all have the same basic structure: a long polymer chain of amino acid subunits linked end to end

An amino acid is this:

An R group can be a single carbon to having a complicated ring structure. There are only 20 aa that naturally occur.
a. **Peptides:**
Synthesis between two aa results in a dipeptide molecule and water.

A Peptide Bond is one that joins two amino acids. A peptide bond creates polarity where Oxygen has a slightly negative charge and Hydrogen has a slightly positive charge. This means that there will be hydrogen bonding (weak bonds) between peptide chains.

b. **Levels of Protein Organization**
There are at least 3 levels of organization, and sometimes 4

I. Primary
   Linear amino acids in joined by peptide bonds

ii. Secondary
   Alpha Helix with Hydrogen bonding between amino acids
   Beta Sheet is also possible with hydrogen bonding

iii. Tertiary
   Due to covalent bonding between R groups, the polypeptide folds and twists, giving it a globular shape

iv. Quaternary
   When two or more polypeptides join together.
7. Nucleic Acids
DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) help code for proteins which are so important! DNA stores all of your genetic information. There is enough DNA to make an entire person in each one of our cells in our body, except which ones?

a. Structure of DNA
All DNA is made up of a phosphate group, a pentose sugar, and a nitrogen containing base. In DNA there are four different bases:
- Adenine
- Thymine
- Guanine
- Cytosine

In RNA there is no Thymine, so it is replaced by Uracil

b. Bonding Rules:
Adenine always binds with Thymine
Guanine always binds with Cytosine

A – T
G – C

Make a complimentary strand:
A T G G C C A A T T T A A G G

c. Double Helix
DNA is double stranded. That means there is a complimentary strand for each parent strand

The DNA molecule forms a alpha helix because of hydrogen bonding between polar bases. This is the polarity of bonding between Hydrogen and Oxygen.
8. ATP (Adenosine Triphosphate)

From *Protein Structure and Function* by Gregory A. Petsko and Dagmar Ringe

---

**Figure 3-32** Essential Cell Biology, 2/e. (© 2004 Garland Science)
In addition to being one of the monomers of nucleic acids, nucleotides have other metabolic functions in cells. When adenosine (adenine plus ribose) is modified by the addition of three phosphate groups instead of one it becomes ATP.

ATP are the cells energy packets! They are used in a wide variety of chemical reactions. When ATP is hydrolysed, ADP (Adenosine Diphosphate) and energy is released. This energy is used to help the cell make other molecules (Proteins and Carbohydrates).