Exercise 4-2
Biochemical Principles

One of the difficulties of studying the molecules of living organisms is that we can't see atoms and molecules. It is difficult to visualize electrons and protons, not to mention the problem of trying to see how atoms bond to each other during chemical reactions, or even what a chemical reaction is. Nevertheless, an understanding of basic principles of chemistry is essential to the understanding of biology. In this laboratory you will use Ball and Stick models to construct an assortment of molecules and to simulate some chemical reactions using these molecules. These exercises will help you to visualize some concepts of chemistry, particularly the features of the chemistry of carbon, and the functional groups which are important to the structure and functioning of the macromolecules of living organisms: carbohydrates, lipids, proteins and nucleic acids.

Bonds in most biological molecules are covalent, which means that electrons are shared between two atoms. Sometimes, particularly when oxygen and/or nitrogen are involved, there is an unequal sharing of electrons. The oxygen or nitrogen atoms tend to pull electrons towards themselves and away from the other end of the molecule. This results in a polar molecule, which has one end with a slightly negative charge and the other end slightly positive.

In addition we will be considering hydrogen bonds. These are much weaker than covalent bonds but they can contribute significantly to the overall structure of a molecule and the interactions of molecules with their environments. Hydrogen bonds are the strong attraction between a hydrogen atom covalently bonded to a nitrogen or oxygen atom of one molecule and an oxygen or nitrogen atom of a second molecule.

In this lab we will use balls and two different lengths of sticks (plastic connectors) to construct models of various biochemical molecules. The balls represent atoms, color coded for each element.

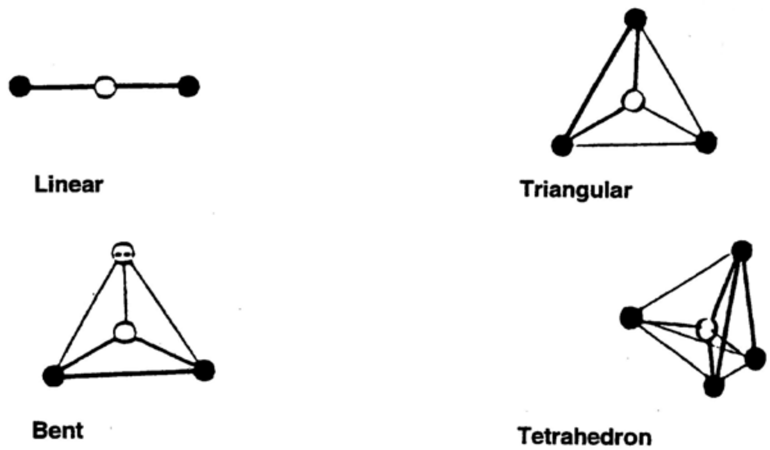
Each ball has holes corresponding to the number of bonding sites where electrons may be shared, donated or accepted. Carbon, for example has four possible bonding sites. The holes are positioned to represent the actual distance between bonding sites and the real bond angles. Similarly the short and long sticks represent single and multiple bonds.

Molecular shape

The shape of molecules is important because it determines how they physically fit together. The function of proteins, for example, is dependent on the particular shape of the protein.

Because electrons have negative charges they are always trying to get away from each other. The arrangement of lone pair electrons and bonds in a molecule determine its shape. Lone pair electrons are those that are not part of the shared electrons of the covalent bond (count up to 8 for each atom).

The basic shapes we are concerned with are pictured below. The lines are not chemical bonds, but lines drawn between atoms to indicate the 3 dimensional shape.



Linear: the atoms are in a line, usually with 2 covalent bonds and no lone pair electrons e.g. oxygen.
Triangular: three sided molecules, with atoms in one plane. These molecules have 3 covalent bonds and no lone pairs e.g. formaldehyde.
Bent: three sided with one or two lone pair electrons on one point e.g. water
Tetrahedron: four sides, all equal triangles. These have 3 covalent bonds and no lone pair electrons. If the four attached atoms are the same, e.g. CCl_4, then the molecule is non-polar. If the 4 atoms are different then the molecule is polar e.g. chloroform $CHCl_3$.

Materials needed:
Molecular model kits
Demonstration models of
- Glucose, linear form
- Glucose, ring form
- Palmitic acid
- Linoleic acid

Activity 1 - Using Models To Construct Small Molecules

Construct each of the following molecules. Note that all of the bonds (holes) of each atom need to be filled with a stick in order for the molecule to be accurate. Nitrogen atoms (the blue balls) are the exception. Only three of its “holes” can be used for bonding. The fourth hole represents an electron pair which is important for acid/base reactions.

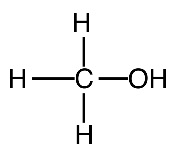
H_2 (Hydrogen gas)
H_2O (water)
O_2 (Oxygen gas)
N_2 (Nitrogen gas)
CO_2 (carbon dioxide)
NH_3 (ammonia)
CH_4 (natural gas - methane)

Activity 2 - Constructing Organic Molecules With Functional Groups

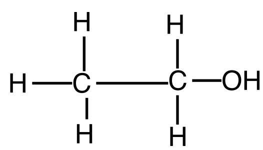
The functional groups are molecular fragments which, when substituted for one or more hydrogen atoms in a hydrocarbon, confer particular chemical properties to the new compound. The functional group can be said to determine the behavior of the molecule. For example, the functional group for the alkanes (the hydrocarbons that have exclusively single bonds and are composed of just hydrogen and carbon) is the hydrogen atom. The properties of all of the alkanes are similar because of this common functional group. The "-" in each of the functional groups we will talk about indicates a bond site where this group can attach to a carbon backbone.

1. Hydroxyl (-OH) Functional Group

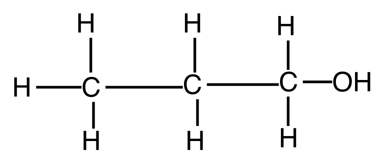
An organic molecule with a hydroxyl functional group attached to it is called an **alcohol**. All alcohols share common properties, for example, they are good fuels (Indy 500 class race cars use methanol) and are toxic. We can usually survive the consumption of ethyl alcohol, C_2H_5OH, only because it is less toxic than the other alcohols. Add a hydroxyl functional group to your ethane by having it replace a hydrogen atom. Do the same thing with your methane and propane molecules. The structures for some possibilities are below.



Methanol



Ethanol

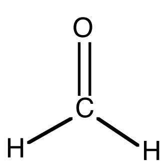


1-Propanol

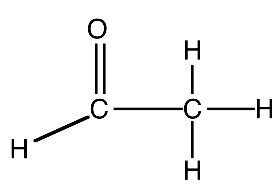
Atoms in molecules can rotate around single bonds, and the molecules themselves are spinning, not fixed in one place.

2. Carbonyl (=O) Functional Groups

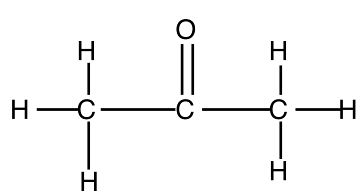
There are two types of carbonyl functional groups, depending on the position of the double bonded oxygen in the molecule. If it is at either end of the molecule it is an aldehyde. If it is attached somewhere in the middle of the molecule it is a ketone. Most aldehydes and ketones are highly toxic. Formaldehyde, the aldehyde formed from methyl alcohol, is used in embalming fluids because it is a good preservative. Nail polish remover contains the ketone, acetone. Ketones can be produced by your body if you go on a high protein, low calorie diet, resulting in a potentially harmful condition called ketosis. Ketosis can be prevented by always including some carbohydrate in any diet plan.



Formaldehyde (methanal)



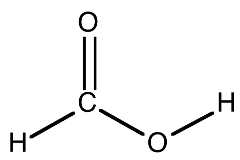
Acetaldehyde (ethanal)



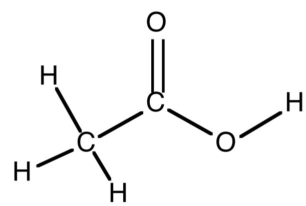
Acetone (propanone)

3. Carboxyl (-COOH) Functional Group

If an organic compound has both the carbonyl (=O) and the hydroxyl (-OH) functional groups attached to the same carbon, they form the **carboxyl** functional group. This is also called a carboxylic acid group because molecules with the carboxyl functional group are organic acids. An acid is a substance which can donate a hydrogen ion in solution. The hydrogen of the carboxyl functional group is liberated as H^+ when the organic acid is in solution. Two organic acids are shown below. Construct a model of acetic acid (vinegar).



Formic acid
(methanoic acid)

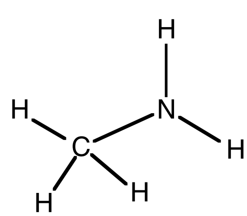


Acetic acid
(ethanoic acid)

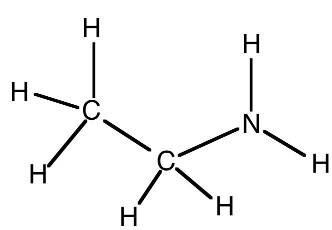
4. Amino ($-NH_2$) Functional Group

The amine group includes a nitrogen and two hydrogens. Amines on their own are not common biological molecules. They are important as components of amino acids, molecules that have both an amine group and a carboxyl group. Amino acids are the building blocks of proteins.

Two examples of amines are shown below. Construct a molecule of ethylamine.



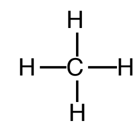
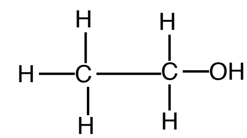
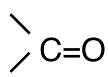
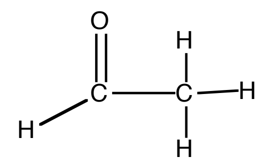
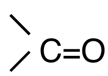
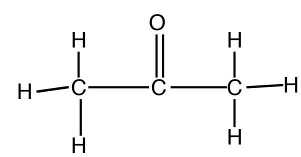
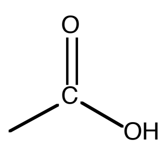
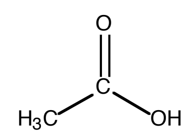
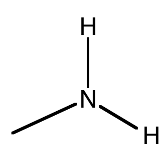
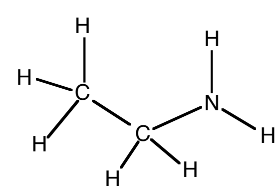
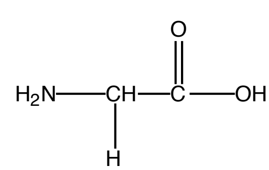
Methylamine



Ethylamine

The table on the next page lists the functional groups that you need to know for Biology 101, along with the types of compounds that are formed by the addition of these functional groups to a hydrocarbon.

Functional Groups

Functional Group Name	Structural Formula	Type of Compound	Example
Hydrogen	-H	Hydrocarbon	
Hydroxyl	-OH	Alcohol	
Carbonyl		Aldehyde	
Carbonyl		Ketone	
Carboxyl		Carboxylic Acid	
Amino		Amine	
Amino + Carboxyl		Amino Acid	

Activity 3 - Constructing Biological Molecules

There are four classes of biological molecules: carbohydrates, lipids, proteins, and nucleic acids. They are all composed of repeating subunits, usually joined together by condensation reactions. In a condensation reaction an -OH from one molecule combines with an -H from a second molecule to form (and remove) a molecule of water, H_2O. The two original molecules are then joined to form a larger molecule. Similarly, large molecules can be split into two smaller ones by inserting a molecule of water in a hydrolysis reaction. The word hydrolysis means splitting with water (lysis = to split, hydro = water). You will be doing condensation and hydrolysis reactions in the next exercises.

1. Carbohydrates

Carbohydrates have the general formula $C_nH_{2n}O_n$, where "n" can mean any number. Their subunits are sugars like glucose $C_6H_{12}O_6$. Some carbohydrates found In living organisms are simple sugars, starch, glycogen and cellulose.

Look at a molecular model of the monosaccharide, glucose, $C_6H_{12}O_6$, in linear and ring form.

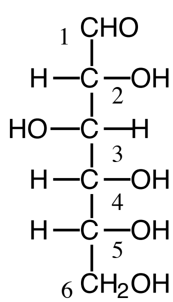


figure a - linear form

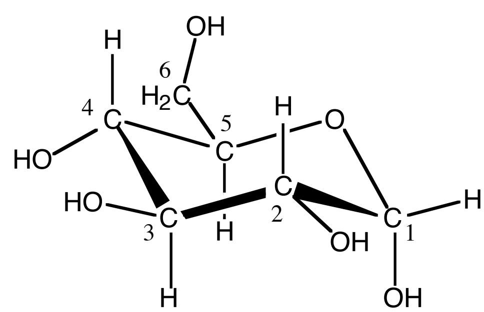


figure b - circular form

Glucose

About 95% of glucose molecules exist in the ring form. The ring form of glucose forms the repeating subunits of starch molecules.

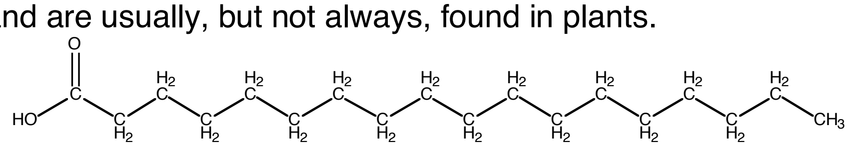
Animals also store sugars as repeating glucose units, similar to starch but in a slightly different configuration - glycogen. Hydrolysis reactions will break down starch and glycogen into their component maltose and glucose molecules. This happens in your body during digestion and other metabolic reactions.

2. Lipids

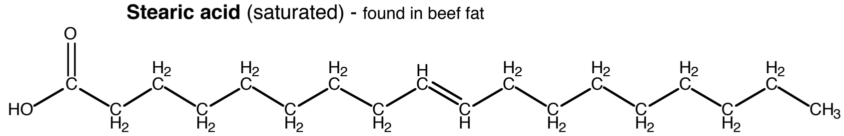
Like carbohydrates, lipids are made of carbon, hydrogen, and oxygen. However they have fewer oxygens per carbon than carbohydrates. Lipids are quite diverse, but the general subunit is a fatty acid. Three types of lipids that are important biologically are fats, phospholipids, and steroids.

a. Fats (triglycerides)

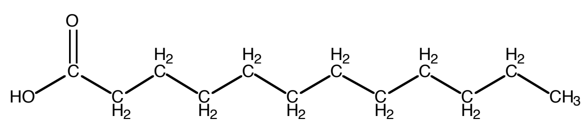
Fats are made up of three fatty acids joined to a glycerol molecule in a condensation reaction as shown below. Fats are also called triglycerides because of this. Glycerol is a 3 carbon molecule with a hydroxyl group attached to each of the carbon atoms. Fatty acids are long chains of carbon atoms with a carboxyl group at the end. They may have double or triple bonds between the carbons. Fatty acids with all single carbon-carbon bonds are called saturated fatty acids, which means they have all the hydrogens they can hold. Saturated fatty acids are solid at room temperature and are usually, but not always, animal in origin. They are the bad guys associated with cardiovascular disease. Unsaturated fatty acids have double or triple bonds, so they can potentially have more hydrogens added into the molecule. They are liquid at room temperature and are usually, but not always, found in plants.



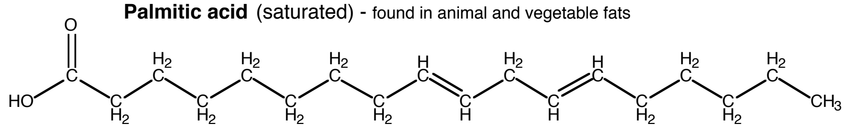
Stearic acid (saturated) - found in beef fat



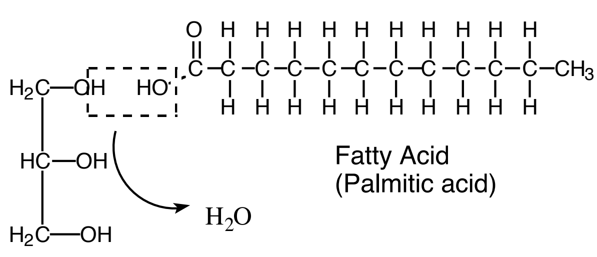
Oleic acid (unsaturated) - found in linseed oil



Palmitic acid (saturated) - found in animal and vegetable fats



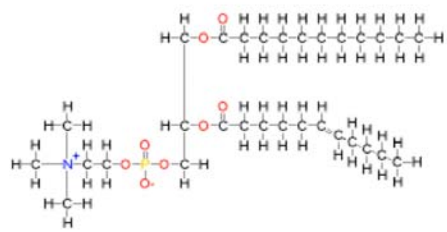
Linoleic acid (unsaturated) - essential fatty acid, found in fish oils



Glycerol

b. Phospholipids

Phospholipids are similar to fats, except that there are only two fatty acids attached to the glycerol molecule. Glycerol's third -OH is bonded to a phosphate group. Phospholipids are important components of cell membranes. Be sure to look closely at the illustration of a phospholipid in your textbook.

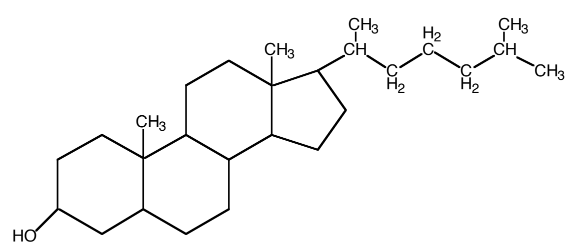


Phospholipid

http://www.biology.lsu.edu/introbio/Link2/phospholipid.gif

c. Steroids

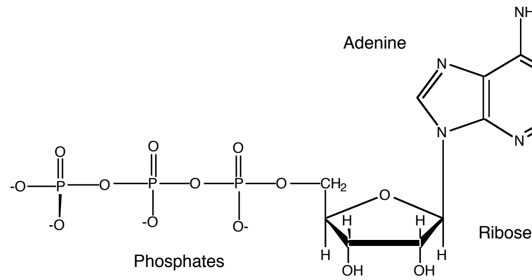
Steroids are complex molecules with several ring structures. Cholesterol is an example of a steroid. It has four rings and a couple of side chains. Note that for simplicity all intersections of lines represent carbons and not all the hydrogens have not been indicated in this diagram of cholesterol. At every point on the rings you should fill in hydrogens to make a total of 4 bonds. See how complicated it gets?.



Cholesterol

3. Nucleic Acids

Nucleic aids and some other biological molecules are made up of subunits called nucleotides. A nucleotide consists of three parts: a 5 carbon sugar, a nitrogen base, and a phosphate group. This class of molecules is called nucleic acids even though some nucleotide molecules are not only found in the nucleus of cells, because the first molecule identified was found in the nucleus. This particular molecule was later determined to be DNA - deoxyribonucleic acid - but by then the name nucleic acids had been given to the whole class. In addition to DNA , some other nucleotide molecules are ribonucleic acid (RNA), adenosine triphosphate (ATP), riboflavin (FAD), and niacin (NAD). We will discuss the structure of DNA and RNA later in the course as well as their functions and those of ATP, NAD, and FAD in biological systems. A molecule of ATP is shown below.

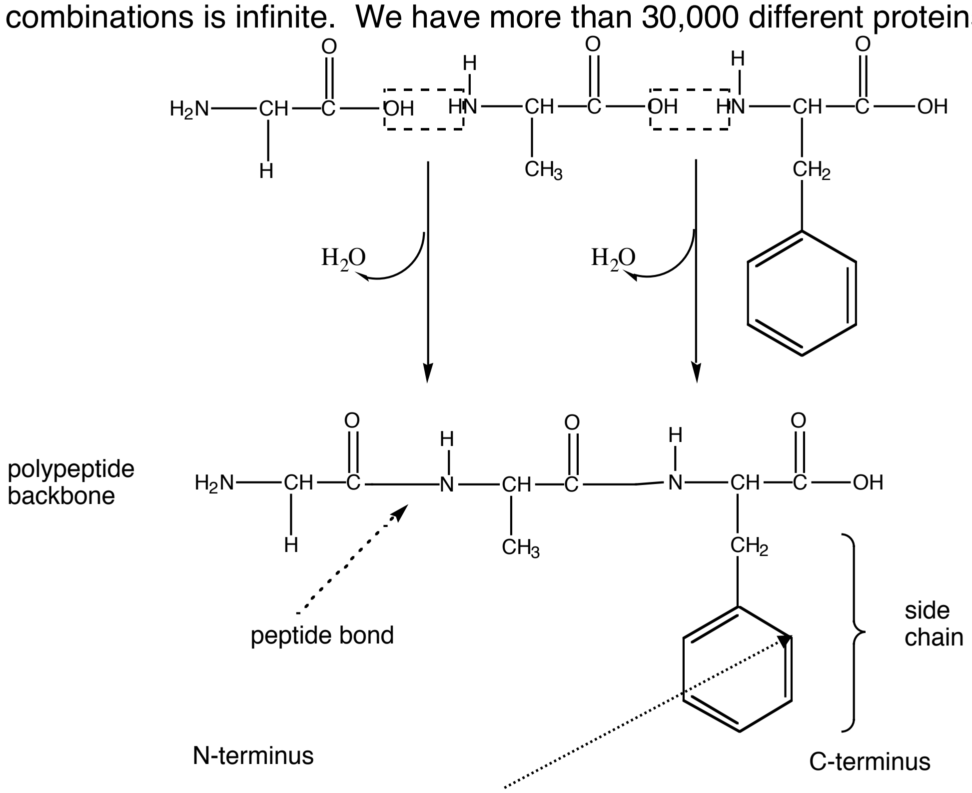


Adenosine Triphosphate (ATP)

4. Proteins

Proteins are made of repeating subunits of amino acids. These molecules have an amine group, a carboxyl group, a hydrogen atom, and an R group attached to a carbon atom. The R group changes with each amino acid, and is the only thing that changes. In glycine the R group is hydrogen (H). In alanine it is a methyl group. The 20 amino acids that make up proteins in humans are shown in appendix C.

Individual amino acids are joined by dehyrdration (condensation) reactions, taking an -H from the amino group of one of the amino acids and an -OH from the carboxyl group of the second amino acid to remove a molecule of water as shown below. The amino end of one amino acid is then attached to the carboxyl end of the other by joining the nitrogen and the carbon. This is called a peptide bond. Two amino acids joined together form a dipeptide; several amino acids constitute a polypeptide. Proteins can be made up of one hundred or more amino acids joined together. Because the 20 amino acids can be joined in any sequence, the number of combinations is infinite. We have more than 30,000 different proteins in our bodies.



Hydrolysis reactions break proteins down into polypeptides, dipeptides and individual amino acids. During the digestion of food, enzymes in our stomach and intestine facilitate these hydrolysis reactions.

Construct an amino acid. Each lab pair should make a different amino acid, so that in the laboratory we will have examples of as many different amino acids as possible. We will join all of the amino acids together to make a polypeptide. Note that no matter how many amino acids we add to the peptide chain we still keep an amino group at one end and a carboxyl group at the other end.

When you have completed all of the exercises please put your molecule kit back together and return the box to the cart.

Worksheet for Exercise 4-2
Biochemical Principles

Name ________________

Molecular shape

Activity 1 - Small Molecules

1. Which of the molecules you made in this activity required double bonds?

2. Which of the molecules you made in this activity have triple bonds?

3. What shape are each of the following molecules? Make the models first, and the shape will be easier to spot.

H_2O	CO_2
N_2	CH_4
O_2	NH_3

Activity 2 - Functional Groups

4. Atoms in molecules can rotate around single bonds, and the molecules themselves are spinning, not fixed in one place. How many different kinds of **3 carbon alcohols** can you make using one hydroxyl group? Draw them here.

5. What is the shortest hydrocarbon chain that can be used to make a ketone? Draw this molecule here.

6. What "shape" do these molecules have in common? - formaldehyde, acetaldehyde, acetone. Look at the part with the functional group.

7. Draw pentaldehyde. (penta means five)

Activity 3 - Biological Molecules

1. Carbohydrates

8. Which carbonyl functional group is in the linear form of glucose - aldehyde or ketone?

9. What other functional group(s) does glucose have?

2. Lipids

10. Waxes are similar to triglycerides but all the fatty acid chains are saturated. Would you expect waxes to be liquid or solid at room temperature? Explain your answer.

11. Would you expect a phospholipid to dissolve in water? Explain your answer.

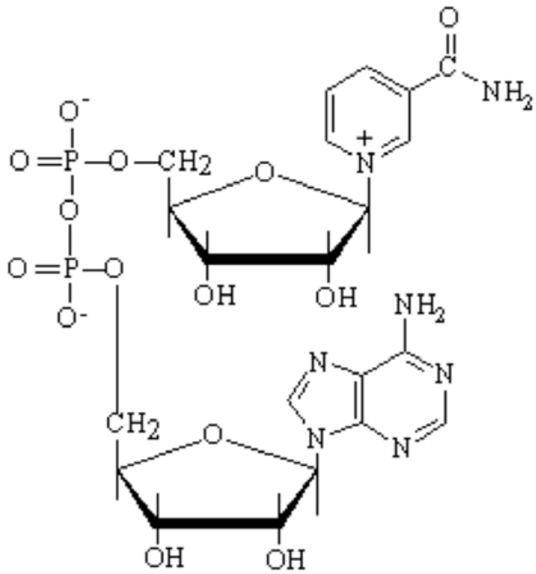
3. Nucleic Acids

12. Below is a diagram of nicotinamide adenine dinucleotide (NAD). It is made up of 2 nucleotides. Circle and label the 3 component parts of each nucleotide.

4. Proteins

13. What is a peptide bond? Draw an example.

14. Draw a molecule of aspartic acid and circle the potential sites for hydrogen bonding.



http://www.gwu.edu/~mpb/coenzymes.htm