What is the chemical nature of carbohydrates, proteins and fats? A deeper understanding.

PURPOSE

To gain a deeper understanding of the nature of growth we will look closer at the chemical nature of carbohydrates, proteins, and fats. We have seen that these are the molecules that not only make up the food that we eat, but these are also the molecules that make up the structure of nearly all living organisms*. The major purpose of this exercise is to help you see how these molecules relate to matter, atoms, and cells.

**(not counting the hard parts of organisms like bones and shells)*

INITIAL IDEAS

On your own: You have probably heard of the word matter. It is even in the title of this course. How would define matter?

Give some (two to three) examples of things that you might considered as matter.

COLLECTING AND INTERPRETING EVIDENCE

YOU WILL NEED

- molecular model kit

To the question "what is matter?", you may have answered that matter is anything that you can see or touch and you would be right. Scientists more formally define matter as anything that takes up space or has mass. For our purposes you can think of mass and weight as the same thing.

All physical objects including food can be considered matter. We have already seen that food is almost entirely composed of carbohydrate, protein, and fat molecules. Therefore these large molecules must also be considered matter.

If food is an example of matter and food is made up of molecules, what are molecules themselves made of? What gives molecules their mass or weight? It turns out that all molecules are made of atoms. In fact all matter is ultimately composed of atoms. **It is the atoms themselves that give matter its mass or weight.**

Atoms can come in a variety of forms. Gold, silver, oxygen, uranium, iron, sodium, and hydrogen are all examples of different types of atoms. Carbohydrates and fats are made up almost entirely of only three different types of atoms: carbon (C), oxygen (O) and hydrogen (H). A fourth type of atom, nitrogen (N), is also needed along with carbon, oxygen and hydrogen to make proteins.

Individual atoms by themselves are often unstable and tend to become more stable by forming chemical bonds with other atoms.

When two or more atoms form chemical bonds with each other, the result is a molecule. For example, when two hydrogen atoms bond with an oxygen atom, the result is a water **molecule.** Water can be written in short hand as H_2O which signifies that one oxygen atom is bonded to two hydrogen atoms. This chemical formula tells you the type of each atom making up the molecule and the number of each type of atom making up the molecule.

Using special kits, we can make models of molecules.

If you open up your kit, you will notice plastic balls of several different colors. The white balls represent hydrogen atoms, the red balls oxygen atoms, the blue balls nitrogen atoms, and the black balls carbon atoms. The white hydrogen atoms have one hole in them, the red oxygen balls have two holes and the blue nitrogen balls have four holes, and black carbon balls also have four holes. These holes represent the number of stable bonds that the atom can form. Thus, hydrogen can form one stable bond, oxygen two, and carbon four. Although nitrogen can form four stable bonds, it normally only forms three.

Atoms often form single bonds with each other. To represent two atoms bonded together by a single bond, you can take a short gray 'stick' and attach an atom to either end. As an example try bonding two hydrogen atoms together. This forms the molecule called molecular hydrogen or H_2. This is a molecule because it consists of two or more atoms bonded together. One way to tell if a molecule is stable is to see if any holes are left open (unoccupied by 'sticks') after you have made the molecule. Notice the hole in each of the hydrogen balls is filled and so you have a fair amount of confidence that you have made a stable molecule.

On your own: If two atoms have two or more holes, then they can form two or more bonds with each other. Try bonding two oxygen atoms together. Notice, when oxygen bonds with another oxygen with just one bond, a hole is left in each of the two oxygen plastic balls. This is an indication that you have not constructed a stable molecule. What would happen if you tried to connect the two oxygen atoms with two bonds? To do this you must use the more flexible long gray sticks. Try bonding two oxygen atoms together in this manner. Do you think you have created a stable molecule? What is your evidence?

Why would you call what you have constructed a molecule?

You have constructed molecular oxygen or O_2. This is the form in which most oxygen in air is found. We call O_2 molecular oxygen so as not to confuse it with a single atom of oxygen. Would a single atom of O be stable. What would be your evidence?

When we breath in oxygen we are actually breathing in O_2 not individual oxygen atoms. Single atoms of O would be quite unstable and tend to form bonds with other atoms to become more stable.

Using the rules that we have been discussing for making stable molecules, try making carbon dioxide or CO_2.

Does your newly constructed molecule have any extra 'holes' in the atoms? If so, keep trying until you have built a molecule consisting of one carbon and two oxygen atoms with all holes filled.

Carbon dioxide is the molecule that we breath out.

Now let's make water or H_2O.

Did you need double bonds or single bonds to make water?

You have made several of the small molecules essential for life to exist (H_2O, CO_2, and O_2). Now we are going to construct some more complicated molecules. We will first construct some important carbohydrates.

Let's start by constructing the simple carbohydrate glucose. The chemical formula for glucose is $C_6H_{12}O_6$. Glucose would therefore be a molecule that consists of _______ carbon atoms, _______ hydrogen atoms, and _______ oxygen atoms. fill in numbers

To arrange these atoms in the proper configuration to make glucose, do the following.

On your own:

STEP 1

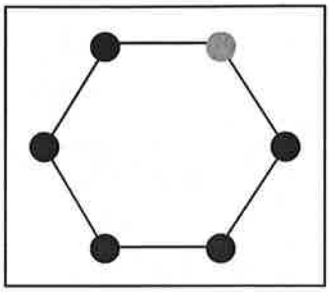
Use single bonds (short gray "sticks") and connect 5 carbon atoms together with one oxygen to form a ring as shown in Figure 2-3. (You will use single bonds throughout the construction of glucose)

What is the shape of this ring structure (how many sides does it have?) _______

How many sides does the structure have that represents glucose in Figure 2-1 (pg. 26)? _______

FIGURE 2-3

Black ball represents carbon atoms. Shaded ball represents oxygen.



STEP 2

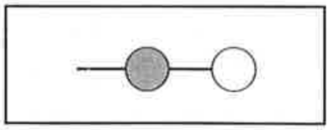
Bond an additional carbon to the carbon that is to the left of the oxygen molecule in the ring. How many carbons are now in the structure that you have constructed so far? _______ How many carbons are in glucose? _______

STEP 3

Bond a hydrogen to an oxygen and place a short gray "stick" in the other hole of the oxygen as shown in Figure 2-4. We will call this structure an OH group. Make four more OH groups.

FIGURE 2-4

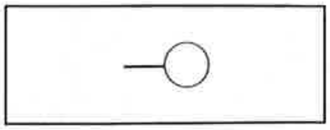
Shaded ball represents oxygen. White ball represents hydrogen.



STEP 4

Obtain 7 hydrogen balls and place a short gray "stick" in the hole of each of the 7 hydrogen balls as shown in Figure 2-5.

FIGURE 2-5



STEP 5

In one of the holes for each of the six carbons, stick one of the hydrogen balls that you constructed in Step 4. In the sixth carbon that you added in Step 2 add the seventh hydrogen ball. That carbon should have two hydrogen atoms bonded to it.

STEP 6

Five carbons should still have one hole without a bond. In each of these holes stick an OH group that you made in Step 3. The structure that you now have made is glucose.

How many hydrogen atoms did you use in making this glucose structure? _______ How many carbon atoms did you use? _______ How many oxygen atoms did you use? _______ Is this consistent with the molecular formula of glucose?________

Does the structural model of glucose that you made appear to be a stable molecule? What is your evidence?

The glucose molecule that you have made can also be visualized in a two dimensional representation as shown in Figure 2-6. Notice that each of the carbons in glucose can be numbered 1-6 (Figure 2-6)

Two glucose molecules can be bonded together. Team up with a group next to you who have also made a glucose molecule. Bond the two glucose molecules together by following Figure 2-7 below and the instructions that follow the figure.

FIGURE 2-6

The six carbons in glucose are often numbered as shown.

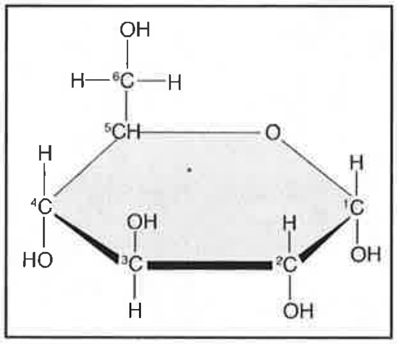
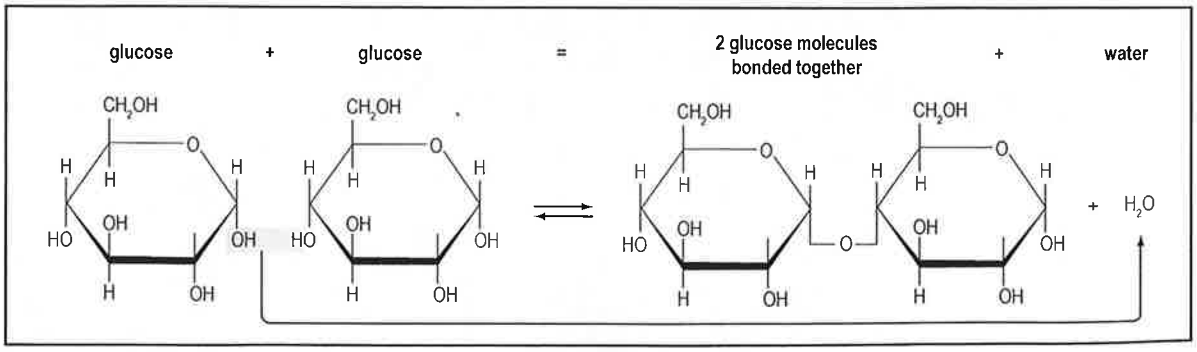


FIGURE 2-7

Each corner of the hexagonal represents a carbon atom



STEP 7

Remove the OH group bonded to the number 1 carbon and an H from the OH group bonded to the number 4 carbon.

STEP 8

Bond the oxygen, whose hydrogen you just removed, to the number one carbon. Does this new molecule appear to be stable? ____________________

What atoms are left over (atoms that you removed from the two glucose molecules that you bonded together)? Can these atoms be bonded together to form a stable molecule? What is that molecule?

How do you think that you could bond another glucose molecule to your two glucose chain?

How might you bond fifty or a thousand glucose molecules together in a chain?

In plants what two complex carbohydrates could this long molecule represent?

In animals what complex carbohydrate would this long molecule represent?

Individual glucose molecules are separated from the chain by the reverse process that was used to bond them together. Separate the glucose molecules from each other. (Note: you must split a water molecule into H and an OH each time a glucose molecule is separated from the chain.) Keep your glucose molecules intact for a later exercise.

Both starch and glycogen can be broken down to individual sugar subunits in our digestive tract. Special proteins called enzymes recognize the chemical bonds between the subunits of the large molecules like starch and glycogen, and these enzymes facilitate the breaking of the bonds.

The bonds holding the sugar molecules together in cellulose are slightly different than those holding the sugar molecules in starch and glycogen. The enzymes that recognize and cut the bonds between the sugar molecules in starch and glycogen cannot recognize and cut the bonds between the sugar molecules in cellulose. That is why the cellulose just passes through our digestive tract and ends up as waste.

We should point out that enzymes are also needed to help put molecules together as when making large molecules like starch, glycogen, and cellulose.

You have now made models that chemically represent several important carbohydrates. You were also shown two dimensional representations of a glucose molecule (Figure 2-6) and glucose molecules being bonded together (Figure 2-7).

Figure 2-8 below shows a representation of a typical fatty acid and a glycerol molecule. Note: the double parallel lines linking one of the carbon and oxygen molecules, C=O, indicates that the carbon is double bonded to the oxygen. The single lines connecting the atoms represent single bonds.)

FIGURE 2-8 **Glycerol**

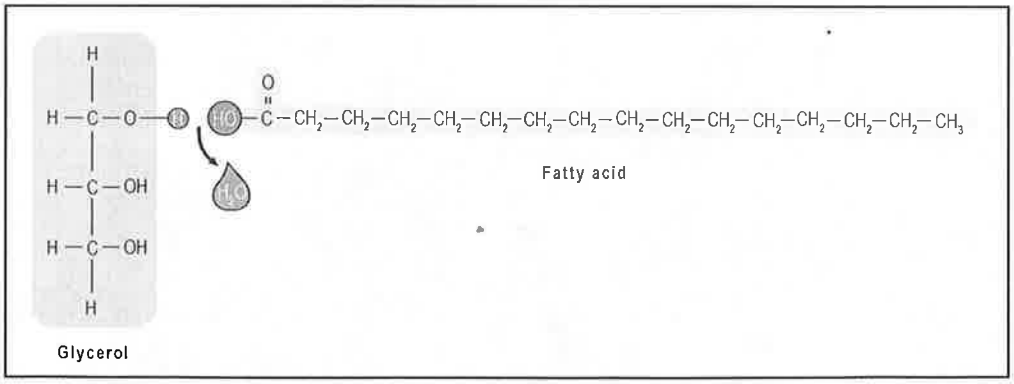
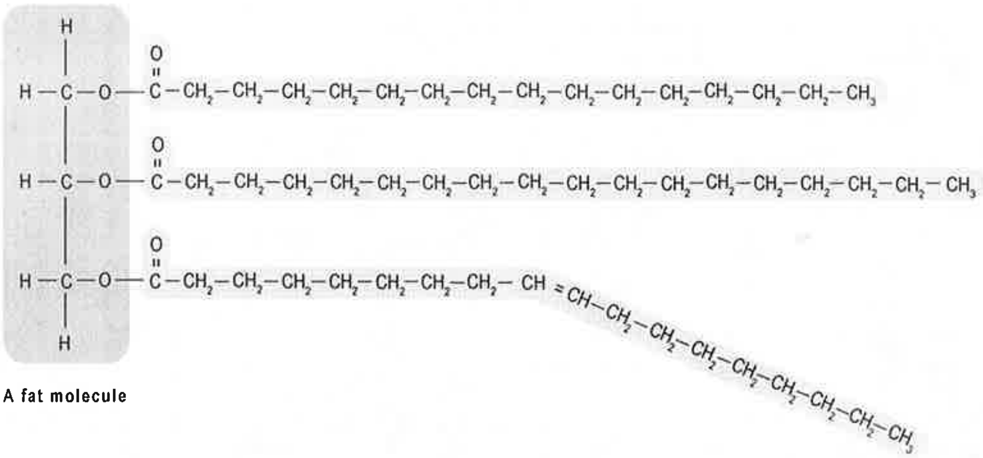


Figure 2-9 below shows how three fatty acids can be bonded to a glycerol molecule to make a fat molecule.

FIGURE 2-9 Fat Molecule



A fat molecule

On your own: In what ways is the bonding of fatty acids to glycerol to make fat similar to the bonding of glucose molecules together to make starch?

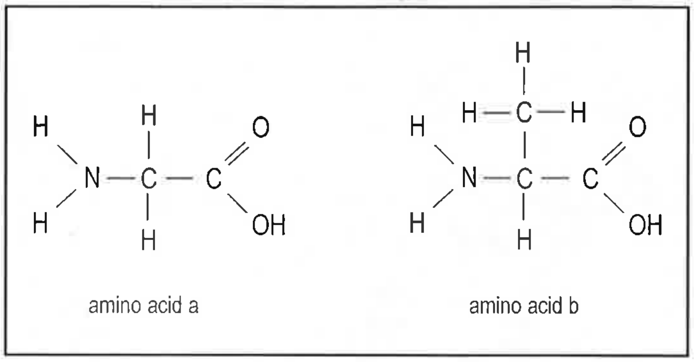
Fats are broken down to 3 fatty acids and glycerol in a similar way that the chain of glucose molecules in starch are separated into individual glucose molecules.

Are the types of atoms making up a fat molecule the same as the types of atoms making up carbohydrates? If they are the same, what are these atoms? If there are one or more different types of atoms, what are they?

What are at least two differences that you notice between a fat molecule and a starch molecule?

Figure 2-10 is a representation of two different amino acids. (Remember there are more than 20 different amino acids.)

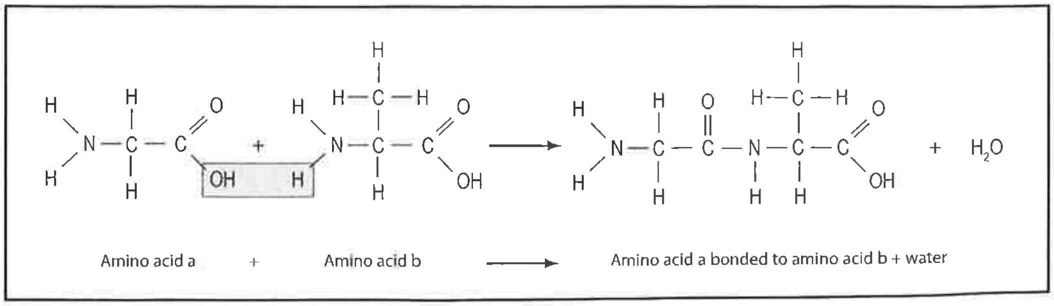
FIGURE 2-10 Amino Acids



Are the atoms making up these amino acids the same that make up carbohydrates and fats? If they are the same, what are these atoms? If there are one or more different types of atoms, what are they?

Figure 2-11 is a representation of how these two amino acids are bonded together.

FIGURE 2-11 Bonded Amino Acids



When these amino acid molecules are bonded together, what type of molecule do they form? (complex carbohydrates, fats, or proteins)

In what way is the bonding of amino acids together to make proteins similar to the bonding of glucose molecules to make starch?

The chain of amino acids can be separated into individual amino acids by the reverse of the process shown in Figure 2-11.

Of the three major biological molecules (carbohydrates, proteins, and fats), carbohydrates and proteins are the only two that can make extensively long molecules. Proteins commonly fold into very complex and intricate three dimensional shapes. Carbohydrates do not.

Because of the intricacies in their shapes and the varieties of their forms, proteins can generally perform a much broader range of functions within a cell than can carbohydrates and fats.

Cells are often likened to factories. **If cells are like factories, then proteins would 1) make up most of the structure of the buildings, 2) make up most of the machinery in the buildings, and 3) serve as factory workers within the buildings**. Carbohydrates and fats can play minor but essential roles as structure, machinery and workers, but the 'bulk' of the carbohydrates and fats have a much different role. This different but very important role is the major topic of the next several activities.

The models give you a good idea of the relative differences in size between atoms and molecules. But how does the size of say a glucose molecule relate to the size of a typical cell? In terms of scale, a glucose molecule somewhere in a cell would be comparable to our glucose model (like the one that we constructed earlier in this activity) located somewhere inside a huge enclosed football stadium.

SUMMARIZING QUESTIONS

On your own:

1. List three molecules that you made in Activity 4. ________________, ________________ and ________________. Explain why these are considered molecules.

2. List three things discussed in Activity 4 that you might consider matter. ________________, ________________ and ________________. Explain why these would be considered matter?

3. Why is it that our digestive tract can break down starch and glycogen, but it cannot break down cellulose?