The Molecules of Cells

3

Human beings have visited the moon, and space shuttles and a space station regularly orbit the Earth. Some people now hope that our goal in space for the next century will be to send people to Mars. One of the attractions of the red planet is the possibility that life exists there. The Viking missions of the 1970s tested Martian soil for the presence of life, and the results were at best inconclusive. In 1996, researchers reported finding traces of organic matter and possible bacterial fossils in a meteorite that may have come from Mars. Most scientists think there is good reason to expect that if we find life elsewhere—on Mars, or perhaps on Titan, a moon of Saturn, or maybe by listening for radio transmissions from other star systems—the life we find will be based on the chemistry of carbon. On Earth, only carbon seems able to form the variety and complexity of stable compounds that can perform the myriad of activities needed to produce life. This chapter is about carbon and carbon compounds in life.

Organizing Your Knowledge

Exercise 1 (Module 3.1)

Web/CD Activity 3A *Diversity of Carbon-Based Molecules*

The great variety of organic compounds results from the ability of carbon atoms to bond with four other atoms, forming branching chains of different lengths. Several hydrocarbon molecules, consisting only of carbon and hydrogen, are shown in Module 3.1. Practice seeing the versatility of carbon by sketching some hydrocarbon molecules of your own, as suggested below.

1. Sketch a hydrocarbon molecule that is a straight chain, containing five carbon atoms and twelve hydrogen atoms, molecular formula C_5H_{12}:

Question: Why does each carbon bond to four other atoms?

2. Now sketch a shorter hydrocarbon chain, with only four carbon atoms:

   Question: What is the molecular formula of the above molecule?

3. Sketch another five-carbon hydrocarbon, but this time include one double bond:

   Question: What is the molecular formula of this molecule?

4. Sketch a five-carbon hydrocarbon molecule that is branched (and contains no double bonds):

   Question: What is the molecular formula of this molecule? What is the term for its relationship to molecule 1 (in this exercise)?

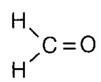
5. Sketch two five-carbon hydrocarbon molecules in the form of rings, one without double bonds and one with one double bond.

   Question: How many hydrogen atoms are in each of these molecules?

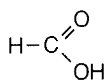
Exercise 2 (Module 3.2)

Web/CD Activity 3B *Functional Groups*

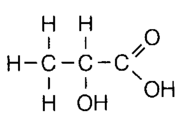
Circle the functional groups that are discussed in this module in the molecules below. Label an example of each of the following: **hydroxyl group, carbonyl group, carboxyl group, amino group**. There are a total of ____ hydroxyl groups, ____ carbonyl groups, ____ carboxyl groups, and ____ amino groups. (The properties of the molecules are described at the right.)



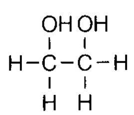
Formaldehyde is the starting point for making many chemicals.



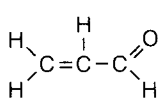
Formic acid gives ant venom its sting.



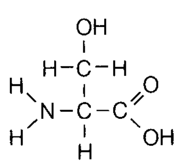
Lactic acid builds up as a waste product in exercising muscles and makes them feel tired.



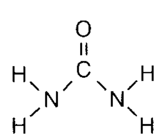
Ethylene glycol is in automobile antifreeze.



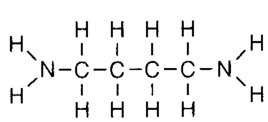
Acrolein is produced when meat is heated; it is the barbecue smell.



Serine is part of many protein molecules.



Urea is a waste product in urine.



Putrescene's name is descriptive; it is produced in rotting flesh.

Exercise 3 (Module 3.3)

Web/CD Activity 3C *Making and Breaking Polymers*

There are four main classes of macromolecules. Most are polymers, assembled from smaller monomers in a process called dehydration synthesis. Hydrolysis breaks the polymers back down to monomers. State whether each of the following relates to dehydration synthesis (D) or hydrolysis (H).

______________ 1. Connects monomers to form a polymer.

______________ 2. Produces water as a by-product.

______________ 3. Breaks up polymers, forming monomers.

______________ 4. Water is used to break bonds between monomers.

______________ 5. Joins amino acids to form a protein.

______________ 6. Glycerol and fatty acids combine this way to form a fat.

______________ 7. Occurs when polysaccharides are digested to form monosaccharides.

______________ 8. —H and —OH groups form water.

______________ 9. Nucleic acid breaks up to form nucleotides.

______________10. Water breaks up, forming —H and —OH groups on separate monomers.

Exercise 4 (Modules 3.3 - 3.7)

Web/CD Activity 3C *Making and Breaking Polymers*
Web/CD Activity 3D *Models of Glucose*
Web/CD Activity 3E *Carbohydrates*

After reading these modules, review carbohydrates by filling in the blanks in the following story.

Carbohydrates are a class of molecules ranging from the simplest sugars, called [1]________________, to giant molecules called [2]________________, built of many sugars. Carbohydrates are the main fuel molecules for cellular work.

Plants make their own carbohydrates, but humans, like all animals, must obtain them from plants or other animals. Imagine eating a piece of whole-wheat bread spread with strawberry jam. It contains a mixture of carbohydrates, along with other macromolecules like [3]________________ and [4]________________. Much of the carbohydrate in the bread itself is in the form of a polysaccharide called [5]________________, which is simply a chain of [6]________________ monomers. The monomers were linked together in the wheat plant in a process called [7]________________ synthesis. As the glucose units joined, [8]________________ was produced as a by-product. When you swallow a bite of bread, digestive juices in the intestine separate the monomers in the opposite reaction, called [9]________________. In the intestine, this is actually a two-step process.

Secretions from the pancreas first break the starch down to maltose, a type of carbohydrate called a [10]________________, which consists of two glucose monomers. Secretions from the walls of the intestine complete the process, breaking each maltose molecule down to two individual glucose molecules.

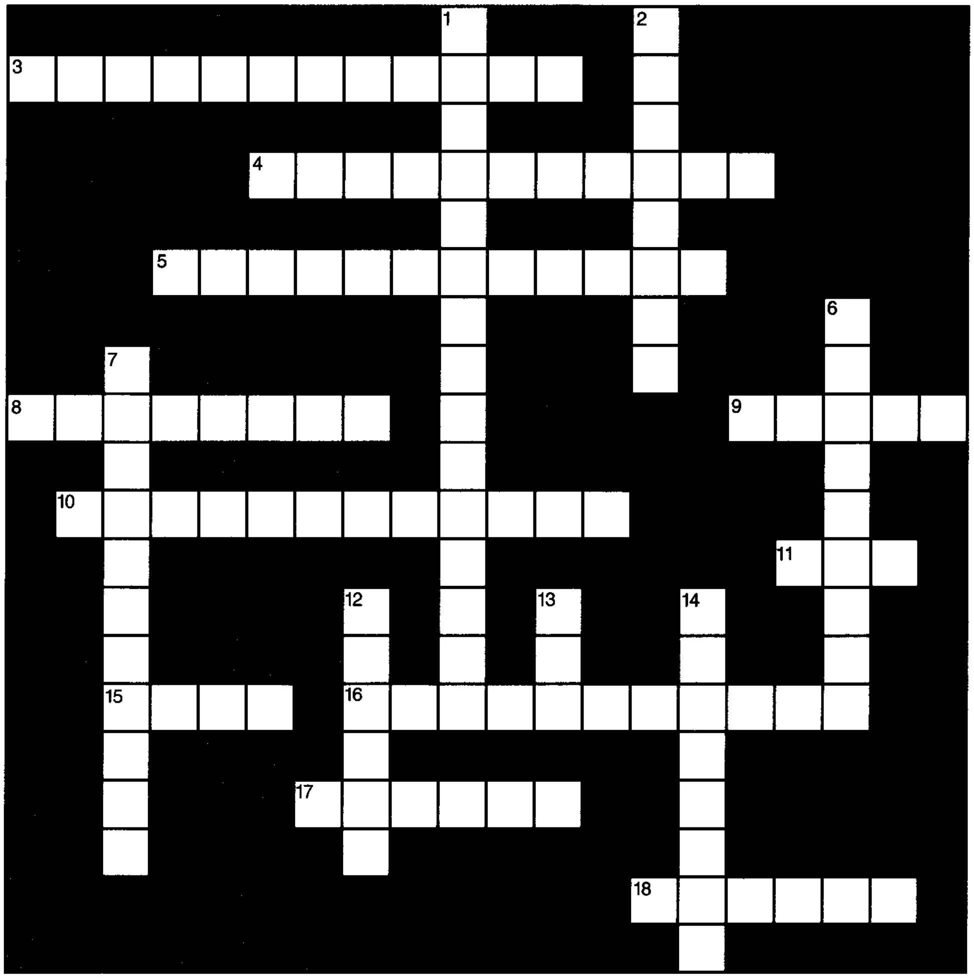
There are other carbohydrates in the bread and jam. Whole-wheat flour contains the tough coats of the wheat seeds. These contain a lot of [11]________________, the fibrous polysaccharide that makes up plant cell walls. Like starch, it is made of glucose monomers, but these monomers are [12]________________ in a different orientation. The human digestive tract is not capable of [13]________________ cellulose, so it passes through the digestive tract unchanged, in the form of [14]________________. Sucrose, a [15]________________ refined from sugar cane or sugar beets, may be used to sweeten the strawberry jam. Each sucrose molecule is hydrolyzed in the small intestine to form one molecule of [16]________________ and one molecule of [17]________________. The jam naturally also contains a small amount of fructose, a [18]________________that is produced by strawberries and is considerably sweeter than sucrose. (If the jam is artificially sweetened, it might contain other molecules whose [19]________________ are similar to natural sugars. These molecules bind to "sweet" [20]________________ on the tongue, producing the sensation of sweetness.)

Once all the carbohydrates have been hydrolyzed to small monosaccharides, they can be absorbed by the body. Glucose and fructose pass through the wall of the intestine and into the bloodstream, which carries them to the liver. Here the fructose is converted to glucose. This process is relatively easy because glucose and fructose are [21]________________, having the same molecular formula, [22]________________, but slightly different structures. Glucose circulates around the body as "blood sugar" and is taken up by the cells for fuel as needed. Extra glucose molecules are taken up by liver and muscle cells and linked together by [23]________________ synthesis to form a polysaccharide called [24]________________. This molecule is similar to [25]________________, except it is more branched. Later the glycogen can be hydrolyzed to release [26]________________ into the blood.

Exercise 5 (Modules 3.8 – 3.10)

Web/CD Activity 3F *Lipids*

Review the structures and functions of lipids by completing the following crossword puzzle.



Across

3. ____ means that hydrogen has been added to unsaturated fats.
4. ____ is a steroid common in cell membranes.
5. A ____ is similar to a fat; found in cell membranes.
8. A fat molecule is composed of ____ and 3 fatty acids.
9. Glycerol and 3 ____ acids make a triglyceride.
10. ____ is another name for "fat."
11. A ____ forms a waterproof coat that keeps a fruit or insect from drying out.
15. Olive and corn ____ are examples of unsaturated fats.
16. Fats with double bonds are said to be ____.
17. ____ is a lipid-containing deposit in a blood vessel.
18. ____ are grouped together because they do not dissolve in water.

Down

1. ____ is when lipid-containing deposits block blood vessels.
2. Female and male sex hormones are examples of ____.
6. Animal fats are said to be ____.
7. Lipids are water-avoiding, or ____ substances.
12. Unsaturated fats contain more ____ bonds than saturated fats.
13. A ____ is a large molecule whose main function is energy storage.
14. ____ steroids are dangerous variants of testosterone.

Exercise 6 (Module 3.11)

Web/CD Activity 3G *Protein Functions*

Everything a cell does involves proteins. Seven classes of proteins are discussed in Module 3.11. Match each of the classes with one of the descriptions below.

________________ 1. Hemoglobin carries oxygen in the blood.

________________ 2. A protein in muscle cells enables them to move.

________________ 3. Antibodies fight disease-causing bacteria.

________________ 4. Collagen gives bone strength and flexibility.

________________ 5. Insulin signals cells to take in and use sugar.

________________ 6. Proteins in seeds provide food for plant embryos.

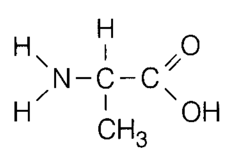
________________ 7. A protein called sucrase promotes the chemical conversion of sucrose into monosaccharides.

Exercise 7 (Modules 3.12 – 3.13)

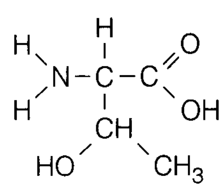
Web/CD Activity 3H *Protein Structure*

Three amino acids not shown in the modules are diagrammed below.

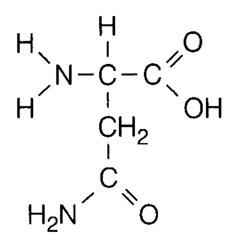
1. Draw a box around the unique R group of each, and label it **R group**.
2. Draw a red circle around the amino group of each, and label it **amino group**.
3. Draw a blue triangle around the acid group of each, and label it **acid group**.



Alanine



Threonine



Asparagine

4. In the space below, sketch the three amino acids to show how they would join to form a tripeptide. What is this chemical reaction called? How many molecules of water would be formed? Show where the water would come from.

Exercise 8 (Modules 3.14 – 3.18)

Web/CD Activity 3H *Protein Structure*

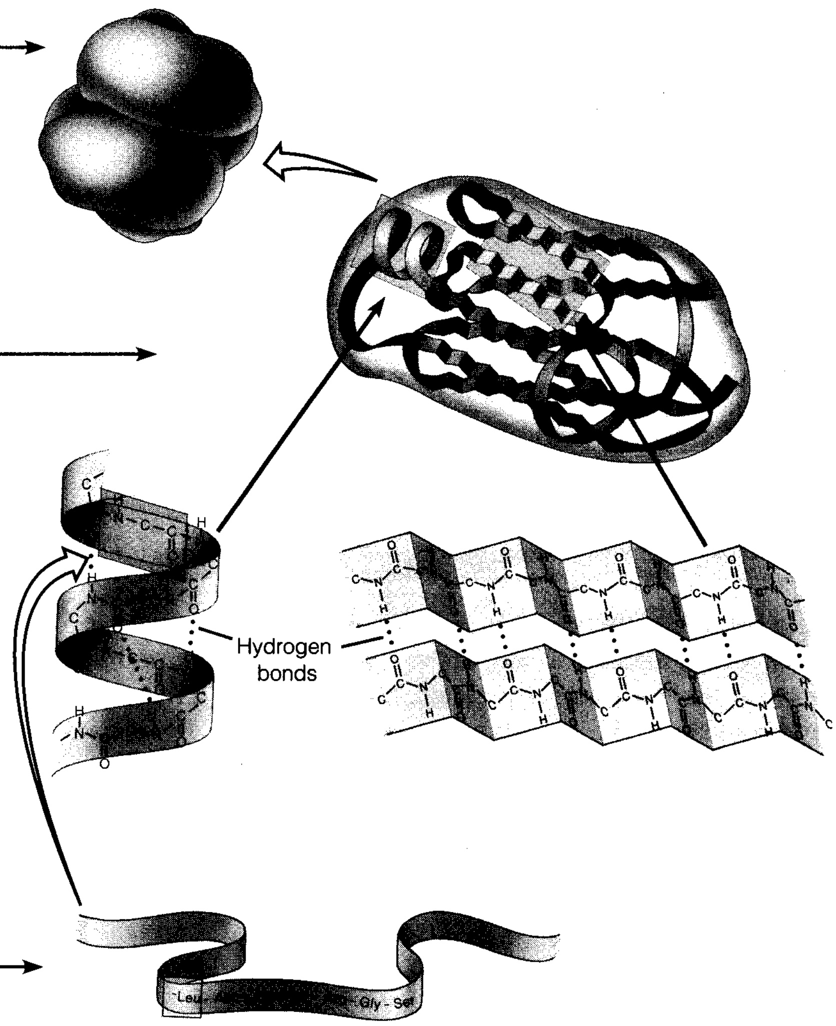
Identify each of the levels of protein structure in the diagrams. Then choose the descriptions from the list below that go with each of the levels.

1. ____________ Structure →
Descriptions: ____________

2. ____________ Structure →
Descriptions: ____________

3. ____________ Structure →
Descriptions: ____________

4. ____________ Structure →
Descriptions: ____________



Choose from these descriptions:

A. Overall three-dimensional shape
B. Amino acid sequence
C. Even a slight change in this can alter tertiary structure.
D. This level occurs in proteins with more than one polypeptide subunit.
E. Coiling and folding produced by hydrogen bonds between —NH and C=O groups
F. Not present in all proteins
G. Level of structure that is held together by peptide bonds
H. Alpha helix and pleated sheet
I. Stabilized by clustering of hydrophobic R groups, hydrogen bonds, and ionic bonds
J. "Globular" or "fibrous" might describe this level of structure.

Exercise 9 (Module 3.20)

Web/CD Activity 3I *Nucleic Acid Functions*
Web/CD Activity 3J *Nucleic Acid Structure*

Nucleic acids are the fourth group of macromolecules discussed in this chapter. Review their structures and functions by matching each of the phrases on the right with a word or phrase from the list on the left. Answers may be used more than once.

A. Phosphate group
B. Deoxyribose
C. A, T, C, G
D. DNA
E. Nucleotide
F. A, U, C, G
G. Double helix
H. Ribose
I. Nitrogenous base
J. RNA

____ 1. Sugar in RNA
____ 2. Overall structure of DNA
____ 3. Short for ribonucleic acid
____ 4. Passed on from parent to offspring
____ 5. Nitrogenous bases of RNA
____ 6. Sugar in DNA
____ 7. Nitrogenous bases of DNA
____ 8. Short for deoxyribonucleic acid
____ 9. DNA works through this intermediary.
____ 10. Nucleotide is sugar, phosphate, and this.
____ 11. Sugar of one nucleotide bonds to this of next nucleotide.
____ 12. Monomer of nucleic acids

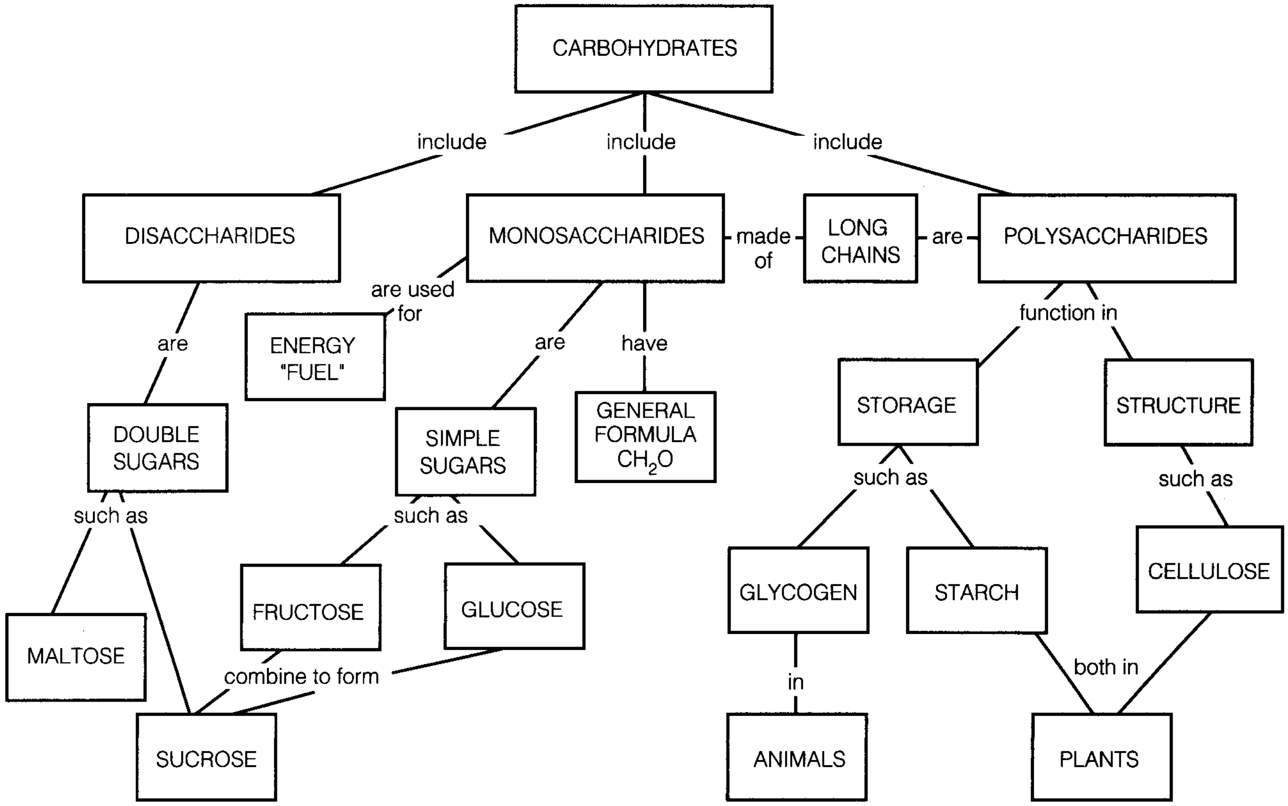
Exercise 10 (Summary)

You may find that making a concept map is a useful way to organize your knowledge. Such a map for the topic of carbohydrates is shown at the top of the next page. A concept map shows how key ideas are connected. Making a concept map can help you learn because it causes you to focus on main concepts and how they are related. It helps you to sort out what is important from unimportant details, and helps you tie your knowledge together into a more meaningful and useful whole.

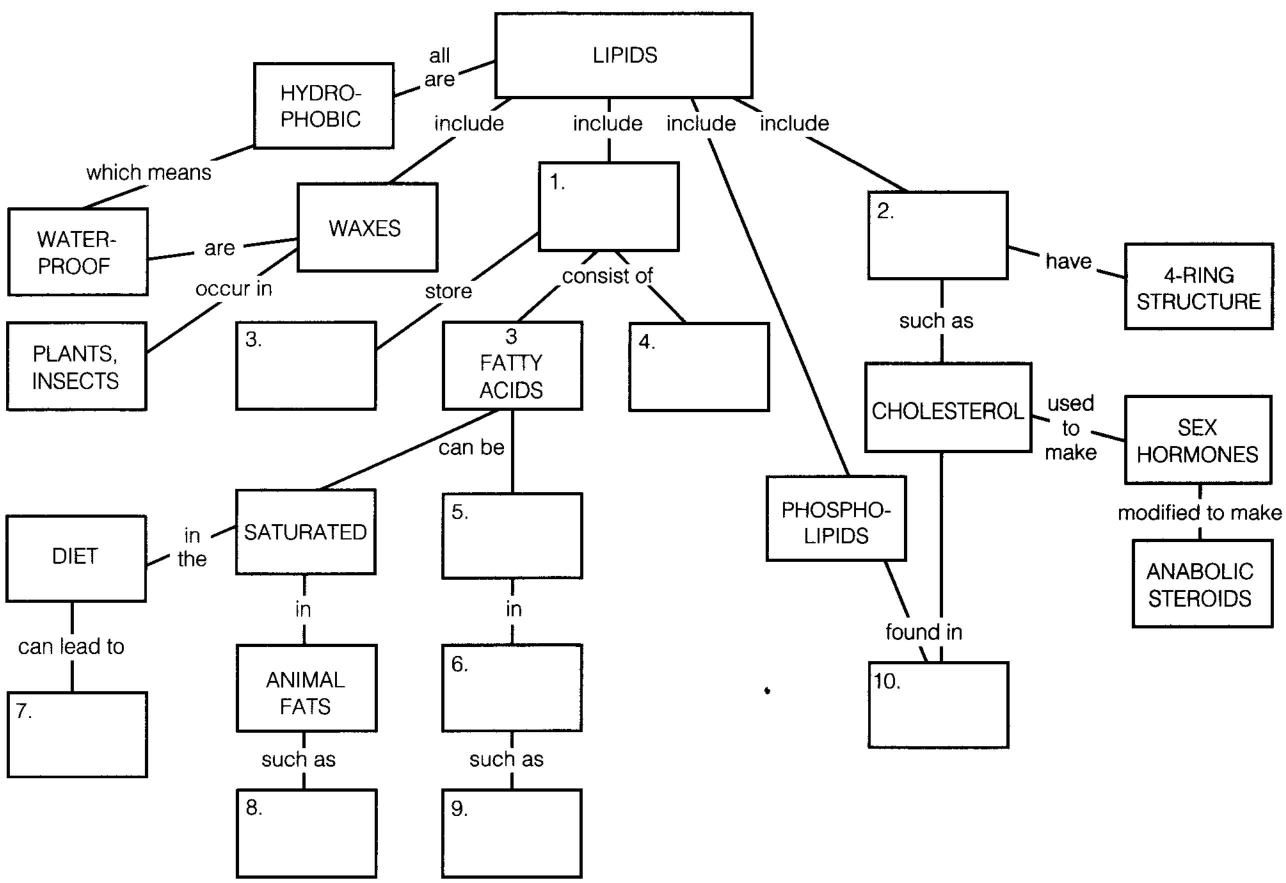
To make a concept map, you must first decide which ideas are most important. Place the biggest, or most inclusive, concept at the top of the page. Just a word or phrase is enough. Cluster subconcepts around it, and cluster sub-subconcepts around them. Draw lines between the concepts to show how they are connected, and describe these connections next to the lines. Again, use only a word or two.

If the topics or connections are not clear, perhaps they are unimportant, or perhaps you are not clear on how they connect, or perhaps they do not really connect. Remember, clarifying relationships is the purpose of making the map. Generally, maps that are more "branched" are more useful than ones with many long straight "chains" of boxes, but there is no one "correct" map for a particular topic.

Focus on the process of making the map, rather than on the map itself. More learning will take place while you are making the map than when you look at the finished product. You might want to "tune up" your maps by comparing them with maps made by other students. After reviewing the following concept maps, on separate paper, try making your own concept maps for proteins and nucleic acids. Keep them simple at first. Remember, "Practice makes perfect!" Also, keep the concept map idea in mind for upcoming chapters.



Practice working with a concept map by filling in the blanks on this map for lipids.



Testing Your Knowledge

Multiple Choice

1. Cellulose is a _____ made of many _____.
   a. polypeptide . . . monomers
   b. carbohydrate . . . fatty acids
   c. polymer . . . glucose molecules
   d. protein . . . amino acids
   e. lipid . . . triglycerides

2. In a hydrolysis reaction, _____, and in this process water is _____.
   a. a polymer breaks up to form monomers . . . consumed
   b. a monomer breaks up to form polymers . . . produced
   c. monomers are assembled to produce a polymer . . . consumed
   d. monomers are assembled to produce a polymer . . . produced
   e. a polymer breaks up to form monomers . . . produced

3. The four main categories of macromolecules in a cell are
   a. proteins, DNA, RNA, and steroids.
   b. monosaccharides, lipids, polysaccharides, and proteins.
   c. proteins, nucleic acids, carbohydrates, and lipids.
   d. nucleic acids, carbohydrates, monosaccharides, and proteins.
   e. RNA, DNA, proteins, and carbohydrates.

4. The characteristic that all lipids have in common is
   a. they are all made of fatty acids and glycerol.
   b. they all contain nitrogen.
   c. none of them is very high in energy content.
   d. they are all acidic when mixed with water.
   e. none of them dissolves in water.

5. A flower's color is determined by the genetic instructions in its
   a. proteins.
   b. lipids.
   c. carbohydrates.
   d. nucleic acids.
   e. all of the above.

6. The most concentrated source of stored energy is a molecule of
   a. DNA.
   b. cellulose.
   c. fat.
   d. protein.
   e. glucose.

7. In some places a protein molecule may twist or fold back on itself. This is called _____ and the coils or folds are held in place by _____.
   a. tertiary structure . . . hydrogen bonds
   b. primary structure . . . covalent bonds
   c. secondary structure . . . peptide bonds
   d. tertiary structure . . . covalent bonds
   e. secondary structure . . . hydrogen bonds

8. A hydrophobic amino acid R group would be found where in a protein?
   a. forming a peptide bond with the next amino acid in the chain
   b. on the outside of the folded chain, in the water
   c. on the inside of the folded chain, away from water
   d. forming hydrogen bonds with other R groups
   e. only at one end of a protein chain

9. The overall three-dimensional shape of a polypeptide is called the
   a. double helix.
   b. primary structure.
   c. secondary structure.
   d. tertiary structure.
   e. quaternary structure.

10. How many different *kinds* of protein molecules are there in a typical cell?
    a. four
    b. twenty
    c. about a hundred
    d. thousands
    e. billions

11. Estrogen, cholesterol, and other steroids are examples of
    a. polysaccharides.
    b. lipids.
    c. polypeptides.
    d. triglycerides.
    e. nucleic acids.

12. The "building blocks" of nucleic acid molecules are called
    a. polysaccharides.
    b. amino acids.
    c. fatty acids.
    d. nucleotides.
    e. DNA and RNA.

Essay

1. Briefly describe the various functions of proteins in the cell and body.
2. Animal fats tend to be solid at room temperature, plant oils more liquid. Explain how a difference in the chemical structure of their molecules causes this physical difference.
3. What forces and bonds maintain the three-dimensional folded shape of a protein molecule? How does this relate to the sensitivity of proteins to changes in their environment?
4. Using circles to represent monosaccharides, show the difference between glucose, maltose, and starch. Maltose is an example of what kind of carbohydrate? Starch is an example of what kind of carbohydrate?
5. Sketch a protein molecule, using squares connected by lines to represent amino acids connected by peptide bonds. Does your protein display primary, secondary, and tertiary structure? Where?

Applying Your Knowledge

Multiple Choice

1. Citric acid makes lemons taste sour. Which of the following is a functional group that would cause a molecule like citric acid to be acidic?
    a. hydroxyl
    b. hydrocarbon
    c. amino
    d. carbonyl
    e. carboxyl
2. Which of the following do nucleic acids and proteins have in common?
    a. They are both made of amino acids.
    b. Their structures contain sugars.
    c. They are hydrophobic.
    d. They are large polymers.
    e. They each consist of four basic kinds of subunits.
3. A biochemist is analyzing a potato plant for the disaccharide sucrose. Where would he be most likely to find it?
    a. in cell membranes
    b. in grains in the cells of underground tubers (potatoes)
    c. in the nuclei of potato cells
    d. in the sap of the potato plant
    e. in the walls of the potato plant cells
4. Which of the following ranks the molecules in the correct order by size?
    a. water . . . sucrose . . . glucose . . . protein
    b. protein . . . water . . . glucose . . . sucrose
    c. water . . . protein . . . sucrose . . . glucose
    d. protein . . . sucrose . . . glucose . . . water
    e. glucose . . . water . . . sucrose . . . protein
5. How does glucose differ from sucrose, cellulose, and starch?
    a. It is a carbohydrate.
    b. It is larger.
    c. The others are polysaccharides.
    d. It is a monosaccharide.
    e. It contains carbon, hydrogen, and oxygen.
6. Steve noticed that his friend Jon had gained a little weight during the holidays. He commented, "Storing up some _____ for the winter, I see."
    a. polysaccharides
    b. triglycerides
    c. nucleotides
    d. polypeptides
    e. steroids
7. How does DNA differ from RNA?
    a. DNA is larger.
    b. One of their nitrogenous bases is different.
    c. They contain different sugars.
    d. DNA consists of two strands in a double helix.
    e. All of the above are differences.
8. Certain fatty acids are said to be essential because the body cannot make them itself; they must be obtained in the diet. If your diet were deficient in these essential fatty acids, you would not be able to make certain
    a. fats.
    b. glycerol molecules.
    c. monosaccharides.
    d. proteins.
    e. You would not be able to make any of the above.

9. Hydrolysis of a protein would produce
   a. amino acids.
   b. monosaccharides.
   c. polysaccharides.
   d. peptide bonds.
   e. nucleotides.

10. Glucose and hexanoic acid each contain six carbon atoms, but they have completely different properties. Glucose is necessary in food; hexanoic acid is poisonous. Their differences must be due to different
    a. monomers.
    b. macromolecules.
    c. hydrolysis.
    d. quaternary structures.
    e. functional groups.

11. Which of the following would probably *not* be affected when a protein is denatured?
    a. primary structure
    b. secondary structure
    c. hydrogen bonds
    d. tertiary structure
    e. All of the above must be affected for the protein to be denatured.

12. Palm oil and coconut oil are more like animal fats than other plant oils. Because they ____ than other plant oils, they can contribute to cardiovascular disease.
    a. contain fewer double bonds
    b. are less saturated
    c. contain more sodium
    d. are less soluble in water
    e. contain less hydrogen

Essay

1. Briefly explain why all starch molecules are pretty much the same, but there are millions of kinds of protein molecules.

2. Specific enzymes in your intestine enable you to break down starch and use the glucose molecules produced by this process. But you cannot break down cellulose. Explain why, in terms of both carbohydrate structure and protein shape.

3. Slight heating is often enough to render a protein nonfunctional. But a polysaccharide such as starch must literally be boiled in acid before it is significantly affected. Explain why.

4. Sketch the structural formulas of two hydrocarbon molecules that are isomers. Be sure the C and H atoms form the correct numbers of bonds. What are the molecular formulas of the molecules? What is identical about the molecules? How do the molecules differ?

5. Fred suffers from a disease that makes it difficult for his cells to produce glycogen. For him, three meals a day are not enough; he needs to snack constantly. Explain why.

6. A tripeptide, a molecule consisting of three amino acids, is a very small protein. Yet a huge variety of tripeptides is possible. Assume that the first, second, and third amino acids can be any of 20 choices. How many different tripeptides could there be? (Hint: Imagine you are stringing beads. If you have 20 colors to choose from, how many three-bead sequences are possible?) How could you calculate the number of possible polypeptides 100 amino acids long? (You probably won't want to actually work it out—it's a *very* large number.)

Extending Your Knowledge

1. Most labels on packaged foods and household products list the chemicals they contain. You can use your knowledge of basic biological chemistry to figure out what the ingredients are. For example, vitamin pills contain folic acid. What makes it an acid? A shampoo contains hydroxypropyl methylcellulose and hydrolyzed soy protein. What kinds of polymers are these? Pretzels are made with hydrogenated cottonseed oil. What does this mean? Poke around in your kitchen cupboards and bathroom cabinet for other examples.

2. Have you used (or been tempted to use) over-the-counter diet supplements (such as the "andro" used by Mark McGuire) to try to lose weight, boost energy, or build muscle? Is there any evidence that these supplements work? Could they be dangerous? How do you get this information?