Chemical Aspects of Life

OBJECTIVES After completing this exercise, the student should be able to:

- Define **organic** and **inorganic** compounds and describe a simple test to distinguish one from the other.
- Name the elements most often found in living organisms.
- Describe the three major groups of organic compounds that compose living organisms, and give examples.
- Distinguish between the three types of carbohydrates, and give an example of each.
- Define: **polymer**, **monomer**, **dehydration synthesis**, and **hydrolysis**.
- Define: **reducing sugar**, **emulsion**, **emulsifier**, **fats**, **oils**, **amino acid**, **glycerol**, **fatty acid**.
- Explain the results of each of the experiments in this exercise using the following: Benedict’s reagent, iodine, and Biuret reagent.
Compounds

All living organisms are composed of compounds, which usually are divided into two groups, organic and inorganic. It once was believed that organic compounds were produced only by living organisms. Now, however, many of the thousands of organic compounds are being made in laboratories. Therefore, a standard definition of an organic compound is one whose molecules contain carbon in the form of chains or rings. It follows that a compound that does not contain carbon arranged in chains or rings is considered an inorganic compound.

ORGANIC COMPOUNDS

Most cells are 70%-90% water. The bulk of their dry weight consists of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and phosphorus (P), variously arranged into four major types of organic compounds:

1. carbohydrates
2. lipids
3. proteins
4. nucleic acids

The more complex members of these categories are made up of chains of smaller molecules—monomers—strung together more or less like beads in a necklace. These complex molecules are called polymers. In living organisms, polymers are made by dehydration synthesis, the loss of a water molecule between each pair of monomers. Conversely, polymers can be digested (broken up into monomers) by the addition of a molecule of water between each pair of monomers. This process is known as hydrolysis.

TEST FOR ORGANIC AND INORGANIC COMPONENTS

Heat the test tubes, each containing a small amount of one of the substances below, over an open flame until all reactions inside the tubes seem to stop. Note the residue in each test tube. If the deposit is black, the substance left on the test tube wall is carbon and the compound was organic. Fill in the chart in Table 3.1.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Organic</th>
<th>Inorganic</th>
</tr>
</thead>
<tbody>
<tr>
<td>sugar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>meat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>table salt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>baking soda</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Carbohydrates

The approximate ratio of carbohydrates is 1 C: 2 H: 1 O. The simplest of the carbohydrates are the simple sugars, or monosaccharides. Of the many types of monosaccharides, the most prevalent in living organisms is glucose. Figure 3.1 shows two forms of glucose in solution, open and closed.

REDUCING SUGARS

Sugars that consist of two monosaccharides linked together are called disaccharides. When monosaccharides join, the sugar is in the closed position (see Figure 3.1). All monosaccharides and some disaccharides have the ability to add electrons to (reduce) other molecules. These sugars are called reducing sugars. Reducing sugars have free carbonyl groups (\(-C=O\)) or (\(-C=O\)) in close proximity to hydroxyl groups (\(-OH\)), and this is where the electrons come from.
Frequently, when two monosaccharides join to form a disaccharide, the carbonyl group gets tied up in the linkage so it is not available to release electrons. This is the case with some disaccharides and all polysaccharides (long polymers of monosaccharides).

Benedict’s reagent, which is used to test for reducing sugars, contains copper ions in alkaline solution. The blue color of the reagent is characteristic of solutions containing copper ions. When Benedict’s reagent is heated in the presence of a reducing sugar, the copper ions are reduced to metallic copper. This forms a precipitate (a substance that settles out of solution), which colors the contents of the tube green to brick red or brown, depending on how much reducing sugar is present. Before the development of paper test strips, this test was used by diabetics to test for sugar (in this case, glucose) in the urine.

1. Because all solutions in this test must be heated, prepare a hot water bath by setting a beaker about half full of tap water on a hotplate. Once steam is rising, turn the temperature back to medium.
2. Number test tubes 1–9 with a wax pencil and place them in a test tube rack.
3. Add the test material to the first eight tubes indicated in Table 3.2. Add 2 ml of Benedict’s reagent to each tube. Mix well.
4. Place in a hot water bath for 2 minutes, remove using a test tube holder, cool, and record the color (in your own words) on Table 3.2.
5. In tube 9 combine the sucrose and acid and heat in the water bath for 10 minutes. Then remove from heat and add the Benedict’s to tube 9. Reheat, cool, and record the results on Table 3.2.

### TABLE 3.2 Test Results: The Reducing Sugar Test

<table>
<thead>
<tr>
<th>Tube</th>
<th>Test Material</th>
<th>Benedict’s</th>
<th>Observations</th>
<th>Test Results (+ or -)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 ml tap water (control)</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 ml glucose</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 ml milk (lactose)</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2 ml apple juice</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2 ml starch</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2 ml molasses (diluted)</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2 ml sucrose</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2 ml 10% HCl (control)</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2 ml sucrose – 2 ml 10% HCl</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 3.3 Test Results: The Starch Test

<table>
<thead>
<tr>
<th>Tube</th>
<th>Test Material</th>
<th>Iodine Observations</th>
<th>Test Results (+ or -)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 ml starch</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 ml glucose</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 ml water</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2 ml sucrose</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>cellulose (cotton)</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>potato (small piece)</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>bread (small piece)</td>
<td>5 drops</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>starch-saliva</td>
<td>5 drops</td>
<td></td>
</tr>
</tbody>
</table>

5. Add iodine to one of these tubes and test the other with Benedict’s solution. From the results of testing tube 8, what did the saliva do to the starch spirals? What did the amylase convert the starch to?

**Lipids**

Lipids are oily or waxy compounds. They are generally insoluble in water but are soluble in organic solvents, such as ether, acetone, carbon tetrachloride, and chloroform.

**TRIGLYCERIDES**

The largest class of lipids, the triglycerides, are composed of two kinds of component molecules: fatty acids and glycerol (an alcohol), as illustrated in Figure 3.2. Triglycerides that are liquid at room temperature are called oils, and those that are solid at room temperature are called fats.

\[
\begin{align*}
\text{GLYCEROL} & \quad \text{FATTY ACID} \\
\begin{array}{c}
H \\
\text{H-C-OH} \\
\text{H-C-OH} \\
\text{H-C-OH} \\
\text{H} \\
\text{OH} \\
\text{OH-(CH}_2\text{)}\text{n-CH}_3 \\
\text{H} \\
\end{array}
\end{align*}
\]

Figure 3.2 Components of a Triglyceride

Lipids are essential to living systems because they serve as concentrated sources of stored energy (nearly twice as rich in calories per gram as carbohydrates or proteins), and in entire organisms as thermal insulation and shock-absorbing pads for organs, bones, and muscles.

**SUDAN STAIN TEST FOR LIPIDS**

A test to determine the presence of lipids is the Sudan stain test.

1. Add three drops of vegetable oil to a test tube half-filled with tap water.
2. Shake thoroughly and observe the way the oil is dispersed only temporarily. This is an emulsion—a mixture of two liquids, each insoluble in the other.
3. Now add a small amount of lipid-specific red Sudan stain and mix again.
4. Add several droppersful of a liquid detergent to the tube and shake again. Allow the tube to stand, and note that the two phases (oil and water) are no longer distinctly separated. Detergent is often termed an emulsifier. Its molecules are water-soluble on one end and lipid-soluble on the other. These surround small oil droplets, water-soluble end out, and allow the droplets to stay suspended in the water.

5. Which layer stained red with the Sudan? 
6. How did the detergent affect the continuity of the lipid layer?
GREASY SPOT TEST FOR LIPIDS

Place a drop of oil and a drop of sucrose solution each on a piece of paper. After 15 minutes, hold the paper toward the light. A transparent to translucent spot is a positive test for a lipid.

Proteins

Proteins are polymers made up of amino acids linked by peptide bonds. The “R” group on the amino acid structural formula shown in Figure 3.3 can be one of 20 different attachments. Therefore, 20 amino acids are commonly found in living systems. The number of ways in which 20 different sub-units can be arranged in a chain is extremely large. Consequently, there is a greater variety of protein molecules in living systems than any other kind of molecule. And the functions that proteins perform are just as varied.

![Amino Acid](image)

Figure 3.3 Amino Acid

BIURET REAGENT

Biuret reagent (a blue-green solution) contains a strong solution of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and a dilute solution of copper sulfate (CuSO₄). If protein is present, the solution will change to violet because of a reaction with the peptide bonds that link the individual amino acids into the protein chain.

BIURET TEST FOR PROTEIN

1. Clean out the test tubes used previously, and, with a wax pencil, number the test tubes 1–7.
2. Add the materials to these tubes as indicated in Table 3.4 and mix well. No heating is needed to produce a reaction.
3. Replace the test tubes in the rack for 2 minutes, and record your results on Table 3.4. Base your conclusion only on the presence or absence of the violet color.

One dropperful is approximately 2 ml.

<table>
<thead>
<tr>
<th>Tube</th>
<th>Test Material</th>
<th>Biuret Reagent</th>
<th>Observations</th>
<th>Test Results (+ or -)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 ml tap water</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 ml sucrose</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 ml albumin</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2 ml milk</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>bread—1 chunk</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ground peanuts—small amount</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2 ml vegetable oil</td>
<td>2 ml</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Review Questions

1. Would Benedict's reagent give a positive reaction with all carbohydrates? Why?

2. Put a drop of iodine on the corner of this page. Does paper contain starch?

3. What chemical elements are present in starch?

4. What is a reducing sugar?

5. What are the component molecules making up triglycerides?

6. Dry cleaners often use carbon tetrachloride. What stains would this remove?

7. What are the building blocks of proteins?

8. How would you determine whether milk contains reducing sugars?

9. What could you say about a substance if it did not turn blue-black with iodine?

10. Is CO₂ (carbon dioxide) considered organic? Why?

11. Biuret reagent is made up of or and .

12. What does “hydrolysis” mean?

13. The hydrolysis of sucrose resulted in the presence of what two sugars? Were they reducing sugars?

14. Define organic and inorganic compounds, and describe a simple test to distinguish one from the other.

15. The elements most often found in living organisms are
16. Describe the three major groups of organic compounds that compose living organisms, and give examples.

a. __________________________ Example __________________________

b. __________________________ Example __________________________

c. __________________________ Example __________________________

17. List the three types of carbohydrates, and give an example of each.

a. __________________________ Example __________________________

b. __________________________ Example __________________________

c. __________________________ Example __________________________

18. Define:

- Polymer __________________________
- Monomer __________________________
- Dehydration synthesis __________________________
- Hydrolysis __________________________

19. Why has water been included as one of the test materials for reducing sugars, starch, and protein? ______

20. Circle or fill in the correct answer:

a. Reducing sugars are usually (monosaccharides, disaccharides, or polysaccharides) that release (protons, neutrons, electrons). These (protons, neutrons, electrons) are added to other molecules.

b. __________________________ is the reagent used to test for reducing sugars. When a reducing sugar is present, the copper ions in the __________________________ reagent are reduced to __________________________.

A __________________________ is formed and settled out of the solution. The color of the __________________________ is anything from green to brick red or brown.

c. __________________________ is the chemical substance used to detect the presence of starch.

d. The largest class of lipids is the __________________________.

e. Lipids are soluble in (water, ether, acetone, chloroform). (Circle any that are applicable.)

21. Why are lipids so important to living systems?

a. __________________________

b. __________________________

c. __________________________

22. Give an example of an emulsion. __________________________

23. Give an example of an emulsifier. __________________________

24. Name the chemical substance used to indicate the presence of lipids. __________________________

25. What reagent is used to test for the presence of protein in foods? __________________________

26. If protein is present, the tested substance will turn __________________________ when mixed with this reagent.