

Chemical and Physical Processes of Digestion

OBJECTIVES

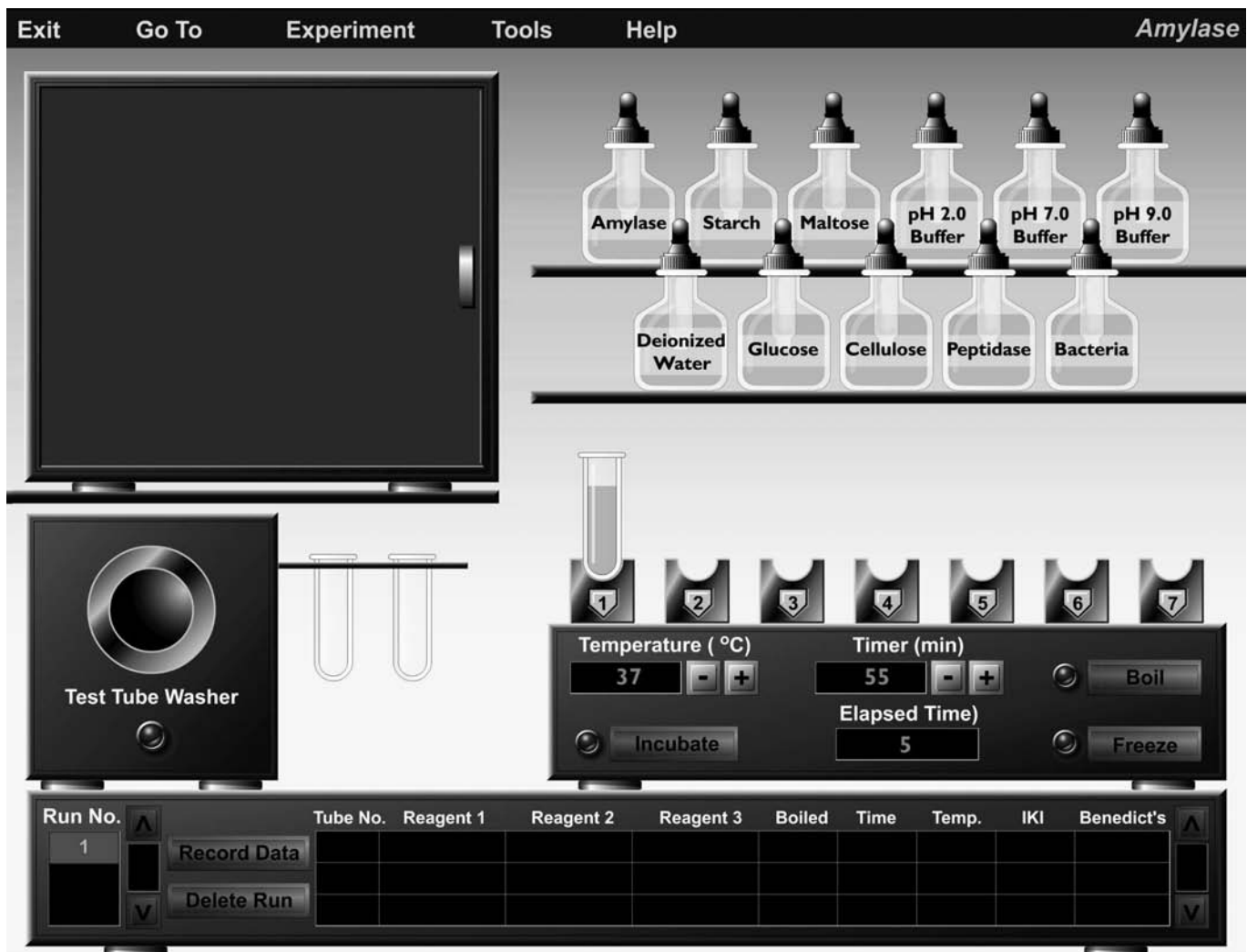
1. To define digestive tract, accessory glands, digestion, hydrolases, salivary amylase, carbohydrates, proteins, lipids, bile salts, pepsin, and lipase
2. To understand the main functions and processes of the digestive system
3. To understand the specificity of enzyme action
4. To explain the impact of temperature and pH levels on enzyme activity
5. To identify the three main categories of food molecules
6. To explain how enzyme activity can be assessed with enzyme assays
7. To identify the main enzymes, substrates, and products of carbohydrate, protein, and fat digestion

The digestive system, also called the *gastrointestinal system*, consists of the **digestive tract** (also *gastrointestinal tract* or *GI tract*) and **accessory glands** that secrete enzymes and fluids needed for digestion. The digestive tract includes the mouth, pharynx, esophagus, stomach, small intestine, colon, rectum, and anus. The major functions of the digestive system are to ingest food, to break food down to its simplest components, to extract nutrients from these components for absorption into the body, and to expel wastes.

Most of the food we consume cannot be absorbed into our bloodstream without first being broken down into smaller subunits. **Digestion** is the process of breaking down food molecules into smaller molecules with the aid of enzymes in the digestive tract. See Figure 8.1b for an overview of chemical digestion sites in the body. Digestive enzymes are **hydrolases**: They *catalyze* (accelerate) the addition of water to food molecules in order to break them down into smaller subunits. For example, when two amino acids join together to form a protein, an —OH^- group is removed from the carboxyl end of one amino acid, and an —H^+ is removed from the amino group of the second amino acid to form a dipeptide bond between the two amino acids plus water. To break down such a protein, a digestive enzyme catalyzes the addition of water (—OH^- plus —H^+) to the dipeptide bond, cleaving the bond to restore the carboxyl group of the first amino acid and the amino group of the second amino acid, and effectively breaks the protein down into two amino acid subunits. Once a food molecule is broken down into its simplest components, the components are absorbed through the epithelial cells that line the intestinal tract and then enter the bloodstream.

In addition to being hydrolases, digestive enzymes are *substrate specific*—they work on some substances but not others. For example, **salivary amylase** is an enzyme in the saliva that breaks down starch (found in foods like corn, potatoes, bread, and pasta) and glycogen (animal starch), but not cellulose (found in the cell walls of plants), even though cellulose is made up of glucose, just like starch and glycogen.

Two factors that play key roles in the efficacy of digestive enzymes are temperature and pH level. An increase in temperature may cause a reaction to speed up, as it causes molecules to move faster and thus increases contact with an enzyme; however, too high a temperature will disrupt molecular bonding that stabilizes enzyme configuration, causing the enzyme to *denature* (i.e., undergo a



(a)

FIGURE 8.1 Chemical digestion. (a) Opening screen of the Amylase experiment. Part (b) follows.

structural change that renders it functionless). In addition, each enzyme has an optimal pH at which it is most active. Within range of this optimal pH, the enzyme will work as expected; beyond the optimal pH, the enzyme may have no effect.

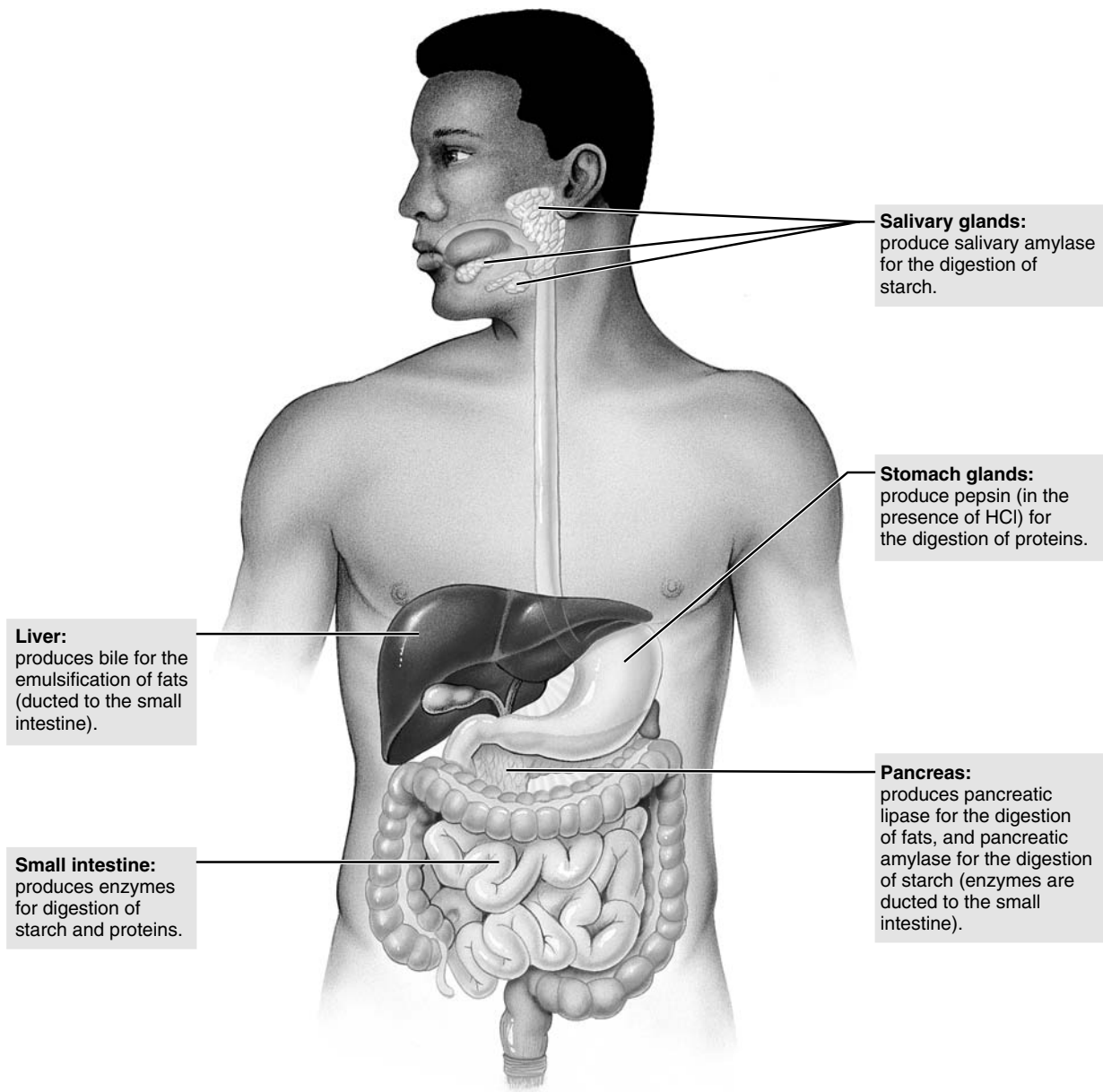
Most food molecules fall into one of the following categories: carbohydrates, proteins, or lipids. **Carbohydrates** are the principal source of calories for most people and include glucose, sugars, and starch. Larger carbohydrates are broken down into *monosaccharides* (simple sugars, such as glucose) before being absorbed into the blood. **Proteins** are very important for growth, especially among young people. Proteins are broken down into *amino acids* before being absorbed into the body to build new proteins. **Lipids**, most of which are *triglycerides* (the major constituents of fats and oils), are not water soluble and thus pose special problems for digestion. Lipase, the enzyme that acts on lipids, is hydrolytic (like all digestive enzymes) and can only work on the surfaces of lipid droplets because the lipids are water insoluble. To increase the rate of digestion by lipase, lipids are first *emulsified* (broken down into smaller droplets) with the aid of **bile salts**, a

cholesterol derivative. Emulsification results in smaller droplets with larger surface areas, making it easier for lipase to bind to substrates and digest lipids. Bile salts also form **micelles**, which aid in the absorption of products of lipid digestion: *fatty acids* and *monoglycerides*.

In the following experiments you will be examining the effects of different digestive enzymes on carbohydrates, proteins, and lipids. To begin, follow the instructions for starting up PhysioEx 8.0 in the Getting Started section at the beginning of this lab manual. From the Main Menu, choose **Exercise 8: Chemical and Physical Processes of Digestion** from the drop-down menu and click **GO**. Then click **Amylase**. The opening screen will appear (see Figure 8.1). This screen will be used for the first two activities, in which you will be testing the effects of salivary amylase on starch and cellulose.

Amylase

Notice the 11 dropper bottles in the top right quadrant of the screen. You will be preparing test tubes containing various



(b)

FIGURE 8.1 (continued) Chemical digestion. (b) A few sites of chemical digestion and the organs that produce the enzymes of chemical digestion.

combinations of the dropper bottle contents. Below the dropper bottles is an incubation unit that will enable you to boil, freeze, and incubate the test tubes. The closed cabinet in the upper left quadrant of the screen is an *assay cabinet*, containing chemicals that you will add to your experimental test tubes in order to interpret your test results. Below the assay cabinet is a *test tube washer* where you will deposit used test tubes. Next to this is a *test tube dispenser* from which you will click test tubes and drag them to the holders in the incubation unit, where you will prepare them for experimentation. Along the bottom of the screen is the data recording box, where you will be recording your experimental data.

ACTIVITY 1

Salivary Amylase and Starch

Starch digestion begins in the mouth with the action of salivary amylase, which is secreted by salivary glands. Salivary amylase breaks starch down into *maltose*, a disaccharide formed from two molecules of glucose. Thus the presence of maltose in an experimental sample would indicate that starch digestion has occurred.

Your goals in this experiment are to test the effects of amylase on starch, determine the optimal pH level at which

amylase works, and observe the effects of temperature on enzyme activity.

- Click the test tube hanging nearest to the incubator, drag it to slot number 1 on top of the incubator, and release the mouse button. The test tube will click into place. Repeat this action, filling slot number 2, slot number 3, and so on, until all seven slots on top of the incubator contain test tubes.
- Fill your seven test tubes with three substances each, as follows:

Test tube #1: starch, deionized water, pH 7.0 buffer
 Test tube #2: amylase, deionized water, pH 7.0 buffer
 Test tube #3: starch, amylase, pH 7.0 buffer
 Test tube #4: starch, amylase, pH 7.0 buffer
 Test tube #5: maltose, deionized water, pH 7.0 buffer
 Test tube #6: starch, amylase, pH 2.0 buffer
 Test tube #7: starch, amylase, pH 9.0 buffer

To do this, click the dropper cap of the desired substance, drag it to the top of the desired test tube, and release the mouse button.

- Click the number “3” under tube #3. The tube will lower into the incubation unit. Then click **Boil**. The tube will boil and then resurface. Note that the only difference between tube #3 and tube #4 is that tube #3 is being boiled.
- Be sure the incubation temperature is set for 37°C and that the timer is set for 60 minutes. If not, click the (+) or (–) buttons accordingly.
- Click **Incubate**. All seven test tubes will be lowered into the incubation unit and gently agitated while incubated. At the end of the incubation period, the tubes will resurface and the door of the assay cabinet will open.

You will notice that there are seven empty test tubes and two dropper bottles in the assay cabinet. The two dropper bottles

contain **IKI** and **Benedict’s** reagents. IKI tests for the presence of starch, while Benedict’s tests for the presence of sugars such as glucose or maltose (which, you will recall, is the product of starch digestion). You will be adding these reagents to your seven experimental test tubes to determine whether or not digestion has taken place.

- Click test tube #1 in slot 1 of the incubator. You will see your cursor change into a miniature test tube. Drag this miniature test tube to the rim of the first tube in the assay cabinet, then release the mouse button. The contents of the miniature test tube will empty into the assay tube.
- Repeat step 6 for the remaining test tubes. Be sure to do this in sequence; that is, do test tube #2, then test tube #3, and so on.
- Once solutions from each of the tubes on the incubator have been transferred to the tubes in the assay cabinet, click the top of the IKI dropper bottle, drag the dropper to the opening of the first tube in the assay cabinet, and release the mouse button. Drops of IKI will be dispensed. The dropper will automatically move across and dispense IKI to the remaining tubes. Note any color changes. A *blue-black* or *gray* color indicates a positive test for starch; a yellow color indicates a negative test. Record your IKI results in the following chart.
- Next, click the dropper top for Benedict’s, drag it to the opening of test tube #1, (in slot 1 of the incubator), and release the mouse button. Drops of Benedict’s will be added to the test tube. Repeat this for the remaining test tubes on top of the incubator.
- After Benedict’s reagent has been added to each test tube on top of the incubator, click **Boil**. All the test tubes will descend into the incubator unit, boil, and resurface. Examine the tubes for color changes. A green, orange, or reddish color indicates the presence of maltose, considered a positive

CHART 1		Results of Activity 1					
Tube No.	1	2	3	4	5	6	7
Additives	starch deionized water pH 7.0 buffer	amylase deionized water pH 7.0 buffer	starch amylase pH 7.0 buffer	starch amylase pH 7.0 buffer	maltose deionized water pH 7.0 buffer	starch amylase pH 2.0 buffer	starch amylase pH 9.0 buffer
Incubation condition	37°C	37°C	boiled, then incubated at 37°C	37°C	37°C	37°C	37°C
IKI test							
Benedict’s test							

Benedict's result. A blue color indicates that no maltose is present, and is considered a negative Benedict's result. Record your data in Chart 1. Use a (+) for a green sample, a (++) for a reddish-brown sample, and a (-) for a blue sample.

11. Click **Record Data** to record your data onscreen. You may also click **Tools** and select **Print Data** for a hard-copy print out of your results.

12. Click and drag each test tube to the opening of the test tube washer and release the mouse button. The tubes will disappear.

What was the purpose of tubes #1 and #2?

What can you conclude from tubes #3 and #4?

What do tubes #4, #6, and #7 tell you about amylase activity and pH levels? (Hint: What variable was changed in the procedure?)

What is the optimal pH for amylase activity? _____

Does amylase work at pH levels other than the optimal pH?

What is the end-product of starch digestion?

In which tubes did you detect the presence of maltose at the end of the experiment?

Why wasn't maltose present in the other tubes?

Salivary amylase would be greatly deactivated in the stomach. Suggest a reason why, based on what you have learned in this activity.

ACTIVITY 2

Salivary Amylase and Cellulose

If there are any test tubes remaining in the incubator, click and drag them to the test tube washer before beginning this activity.

In the previous activity we learned that salivary amylase can digest starch. In this activity we will test to see whether or not salivary amylase digests cellulose, a substance found in the cell walls of plants. We will also investigate whether bacteria (such as that found in the stomachs of cows and other ruminants) will digest cellulose, and whether peptidase (a pancreatic enzyme that breaks down peptides) will digest starch.

1. Click the test tube hanging nearest to the incubator, drag it to slot number 1 on top of the incubator, and release the mouse button. The test tube will click into place. Repeat this action, filling slot number 2, slot number 3, and so on, until all seven slots on top of the incubator contain test tubes.

2. Fill your seven test tubes with three substances each, as follows:

Test tube #1: amylase, starch, pH 7.0 buffer
 Test tube #2: amylase, starch, pH 7.0 buffer
 Test tube #3: amylase, glucose, pH 7.0 buffer
 Test tube #4: amylase, cellulose, pH 7.0 buffer
 Test tube #5: amylase, cellulose, deionized water
 Test tube #6: peptidase, starch, pH 7.0 buffer
 Test tube #7: bacteria, cellulose, pH 7.0 buffer

To do this, click the dropper cap of the desired substance, drag it to the top of the desired test tube, and release the mouse button.

3. Click the number "1" under tube #1. The tube will lower into the incubation unit. Then click **Freeze**. The tube will be frozen and then resurface.

4. Be sure the incubation temperature is set for 37°C and that the timer is set for 60 minutes. If not, click the (+) or (-) buttons accordingly.

5. Click **Incubate**. All seven test tubes will be lowered into the incubation unit and gently agitated while incubated. At the end of the incubation period, the tubes will resurface and the door of the assay cabinet will open.

Again, you will notice that there are seven empty test tubes and the IKI and Benedict's dropper bottles in the assay cabinet. Recall that IKI tests for the presence of starch, while Benedict's tests for the presence of glucose or maltose. IKI turns blue-black in the presence of cellulose as well as starch. You will be adding these reagents to your seven experimental test tubes to determine whether or not digestion has taken place.

6. Click test tube #1 in slot 1 of the incubator. You will see your cursor change into a miniature test tube. Drag this miniature test tube to the rim of the first tube in the assay cabinet, then release the mouse button. The contents of the miniature test tube will empty into the assay tube.

CHART 2		Results of Activity 2					
Tube No.	1	2	3	4	5	6	7
Additives	amylase	amylase	amylase	amylase	amylase	peptidase	bacteria
	starch	starch	glucose	cellulose	cellulose	starch	cellulose
	pH 7.0 buffer	pH 7.0 buffer	pH 7.0 buffer	pH 7.0 buffer	deionized water	pH 7.0 buffer	pH 7.0 buffer
Incubation condition	frozen, then incubated 37°C	37°C	37°C	37°C	37°C	37°C	37°C
IKI test							
Benedict's test							

7. Repeat step 6 for the remaining test tubes. Be sure to do this in sequence; that is, do test tube #2, then test tube #3, and so on.

8. Once solutions from each of the tubes on the incubator have been transferred to the tubes in the assay cabinet, click the top of the IKI dropper bottle, drag the dropper to the opening of the first tube in the assay cabinet, and release the mouse button. Drops of IKI will be dispensed. The dropper will automatically move across and dispense IKI to the remaining tubes. Note any color changes. A *blue-black* or *gray* color indicates a positive test for starch; a yellow color indicates a negative test. Record your IKI results in the following chart.

9. Next, click dropper top for Benedict's, drag it to the opening of test tube #1 (in slot 1 of the incubator), and release the mouse button. Drops of Benedict's will be added to the test tube. Repeat this step for the remaining test tubes on top of the incubator.

10. After Benedict's reagent has been added to each test tube on top of the incubator, click **Boil**. All the test tubes will descend into the incubator unit, boil, and resurface. Examine the tubes for color changes. A green, orange, or reddish color indicates the presence of glucose or maltose, considered a positive Benedict's result. A blue color indicates that no glucose or maltose is present, and is considered a negative Benedict's result. Record your data in Chart 2. Use a (+) for a green sample, a (++) for a reddish-brown sample, and a (-) for a blue sample.

11. Click **Record Data** to record your data onscreen. You may also click **Tools** and select **Print Data** for a hard copy print out of your results.

12. Click and drag each test tube to the opening of the test tube washer and release the mouse button. The tubes will disappear.

Which tubes showed that starch or cellulose was still present?

Which tubes tested positive for the presence of reducing sugars?

What was the effect of freezing tube #1?

How does the effect of freezing differ from the effect of boiling?

What is the smallest subunit into which starch can be broken down?

Does amylase use cellulose as a substrate? Hint: Look at the results for tube 4.

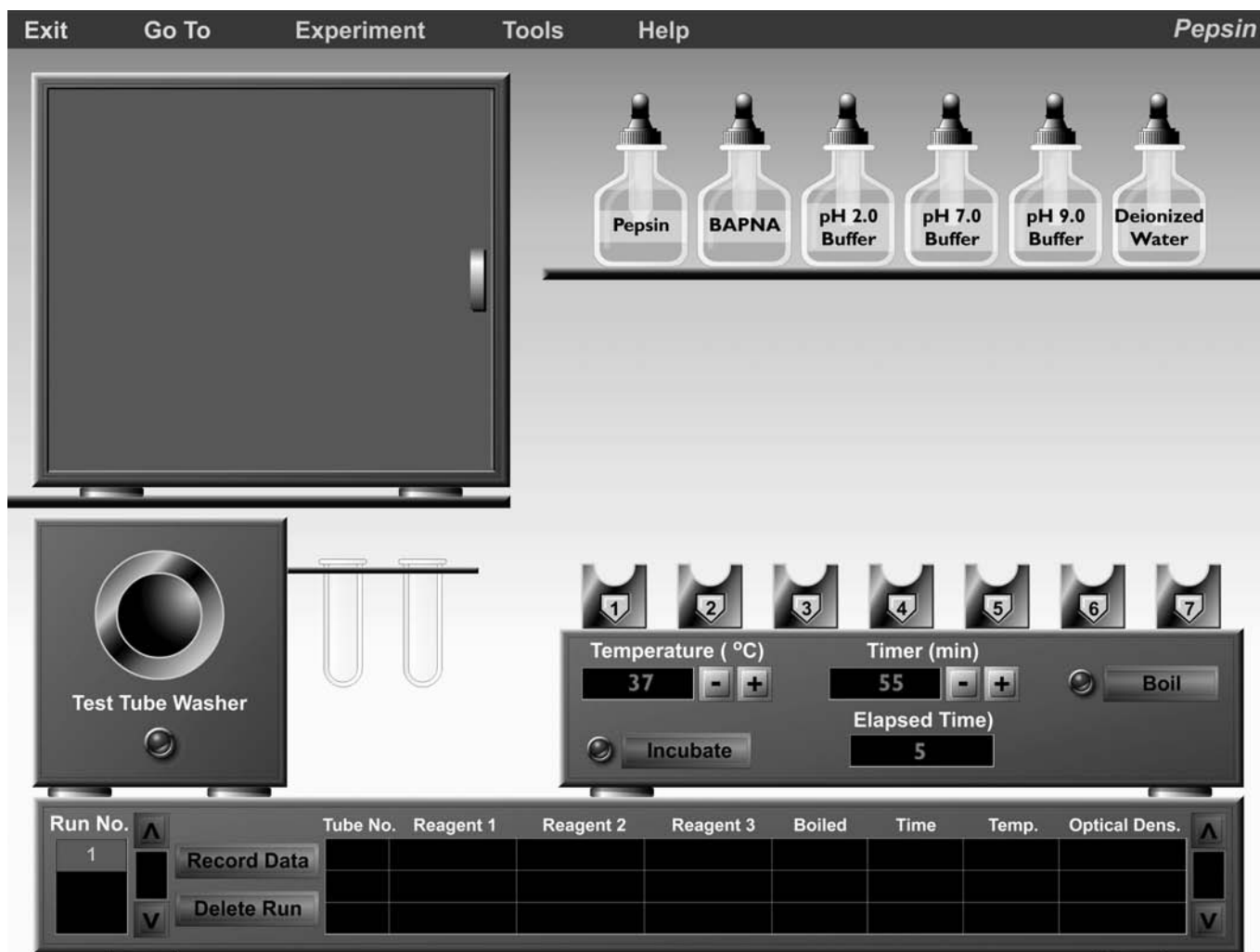


FIGURE 8.2 Opening screen of the Pepsin experiment.

Popcorn and celery are nearly pure cellulose. What effect did the addition of bacteria have on the digestion of cellulose?

What was the effect of the enzyme peptidase, used in tube #6? Explain your answer, based on what you know about peptidase and its substrate.

Pepsin

Proteins are composed of subunits known as *amino acids*. When subjected to enzyme activity, proteins are broken down to their amino acid components. **Pepsin** is an example of an enzyme that breaks down protein. Pepsin is secreted by stomach glands as an inactive proenzyme, *pepsinogen*, which is converted to pepsin by the cleavage of acid-labile linkages in

the acidic (low pH) environment of the stomach. The extent to which protein in the stomach is hydrolyzed or digested is significant but variable. It is estimated that 15% of dietary protein is reduced to amino acids by pepsin. Most protein digestion occurs in the duodenum of the small intestine.

ACTIVITY 3

Pepsin Digestion of Protein

In this next activity you will be investigating the effects of pepsin on BAPNA, a synthetic protein. Click **Experiment** at the top of the screen and then select **Pepsin**. You will see the screen shown in Figure 8.2. The screen is slightly different from the one you worked with for the “Amylase” activities. Notice that the dropper bottles now include bottles for pepsin and for BAPNA. BAPNA is colorless and transparent in solution but will become yellow if digested by an enzyme like pepsin—you will not need to add additional reagents to determine whether or not enzyme activity has occurred.

1. Click the test tube hanging nearest to the incubator, drag it to slot number 1 on top of the incubator, and release the mouse button. The test tube will click into place. Repeat this

action, filling slot number 2, slot number 3, and so on, until six of the seven slots on top of the incubator contain test tubes. (Unlike the previous activities, you will be working with only six test tubes here.)

2. Fill your six test tubes with three substances each, as follows:

Test tube #1: pepsin, BAPNA, pH 2.0 buffer

Test tube #2: pepsin, BAPNA, pH 2.0 buffer

Test tube #3: pepsin, deionized water, pH 2.0 buffer

Test tube #4: deionized water, BAPNA, pH 2.0 buffer

Test tube #5: pepsin, BAPNA, pH 7.0 buffer

Test tube #6: pepsin, BAPNA, pH 9.0 buffer

To do this, click the dropper cap of the desired substance, drag it to the top of the desired test tube, and release the mouse button.

3. Click the number “1” under tube #1. The tube will lower into the incubation unit. Then click **Boil**. The tube will boil and then resurface.

4. Be sure the incubation temperature is set for 37°C and that the timer is set for 60 minutes. If not, click the (+) or (–) buttons accordingly.

5. Click **Incubate**. All six test tubes will be lowered into the incubation unit and gently agitated while incubated. At the end of the incubation period, the tubes will resurface and the door of the assay cabinet will open.

When the assay cabinet opens, you will see a *spectrophotometer*, an instrument that measures the amount of light absorbed (called *optical density*) by a solution. You will be using the spectrophotometer to measure how much yellow dye was released when BAPNA was “digested.” To do this, you will individually drag each test tube into the spectrophotometer and click **Analyze**. The spectrophotometer will shine a light through the solution to measure its optical density. The

greater the optical density, the more BAPNA digestion by pepsin occurred.

6. Click tube #1, drag it to the spectrophotometer, and release the mouse button.

7. Click **Analyze**.

8. Note the optical density reading for this test tube. Record it in the chart below.

9. Remove the test tube and return it to its slot on top of the incubator.

10. Repeat steps 6–9 for the remaining test tubes.

11. After all of the tubes have been read, click **Record Data** to record your data on screen.

12. Drag each test tube to the test tube washer to dispose of them.

13. Click **Tools** → **Print Data** to print your data.

Which pH value allowed for maximal hydrolysis of BAPNA?

What effect did the boiling have on enzyme activity?

Which test tubes led you to this conclusion?

Would freezing have the same effect? Why or why not?

CHART 3		Results of Activity 3					
Tube No.	1	2	3	4	5	6	
Additives	pepsin	pepsin	pepsin	deionized water	pepsin	pepsin	
	BAPNA	BAPNA	deionized water	BAPNA	BAPNA	BAPNA	
	pH 2.0 buffer	pH 2.0 buffer	pH 2.0 buffer	pH 2.0 buffer	pH 7.0 buffer	pH 9.0 buffer	
Incubation condition	boiled, then incubated at 37°C	37°C	37°C	37°C	37°C	37°C	
Optical density							

Which test tubes were your “controls”?

What were they “controlling” for?

What was pepsin’s affect on BAPNA?

Using the simulation, design an experiment that would allow you to test how the amount of BAPNA digestion varies with time. What is your conclusion?

Using the simulation, design an experiment that would allow you to test whether or not temperature has any affect on BAPNA digestion. What is your conclusion?

Lipase

In a normal diet, the primary lipids are triglycerides, the major constituents of fats and oils. Lipids are insoluble in water, and thus they must first be emulsified (broken down into smaller droplets, thus increasing their surface areas) before a digestive enzyme like **lipase** can work effectively on them. In the small intestine, lipids are emulsified by bile, a yellow-green fluid produced by the liver. The resulting bile-covered droplets have relatively large surface areas, allowing water-soluble lipase enzymes easier access to substrates. Lipase then hydrolyzes the lipid droplets to fatty acids and monoglycerides, the end-products of lipid digestion. Hydrolysis of lipids also forms micelles, small molecular aggregates that increase absorption of the products of lipid digestion. Lipases found in pancreatic juice are responsible for the digestion of most of the lipids present in normal diets.

ACTIVITY 4

Lipase, Bile, and Lipid Digestion

Click **Experiment** at the top of the screen and then select **Lipase**. You will see the screen shown in Figure 8.3. Notice that the dropper bottles now include lipase, vegetable oil, and bile salts. Notice also that the dropper bottles containing pH buffers are now color-coded—this will help you analyze your results later in the experiment. You will be testing the effects of lipase and bile on the digestion of a lipid: vegetable oil.

1. Click the test tube hanging nearest to the incubator, drag it to slot number 1 on top of the incubator, and release the mouse button. The test tube will click into place. Repeat this

action, filling slot number 2, slot number 3, and so on, until all seven slots on top of the incubator contain test tubes.

2. Fill your seven test tubes with four substances each, as follows:

Test tube #1: lipase, vegetable oil, bile salts, pH 7.0 buffer

Test tube #2: lipase, vegetable oil, bile salts, pH 7.0 buffer

Test tube #3: lipase, vegetable oil, deionized water, pH 7.0 buffer

Test tube #4: lipase, deionized water, bile salts, pH 9.0 buffer
Test tube #5: deionized water, vegetable oil, bile salts, pH 7.0 buffer

Test tube #6: lipase, vegetable oil, bile salts, pH 2.0 buffer

Test tube #7: lipase, vegetable oil, bile salts, pH 9.0 buffer

To do this, click the dropper cap of the desired substance, drag it to the top of the desired test tube, and release the mouse button.

3. Click the number “1” under tube #1. The tube will lower into the incubation unit. Then click **Boil**. The tube will boil and then resurface.

4. Be sure the incubation temperature is set for 37°C and that the timer is set for 60 minutes. If not, click the (+) or (–) buttons accordingly.

5. Click **Incubate**. All seven test tubes will be lowered into the incubation unit and gently agitated while incubated. At the end of the incubation period, the tubes will resurface and the door of the assay cabinet will open.

You will see a pH meter in the assay cabinet. Digestion of vegetable oil by lipase will release fatty acids, which decrease pH levels. Thus you will be using the pH meter to help you detect the presence of fatty acids (and, consequently, evidence of digestion) by comparing the pH levels of your samples now to their original pH levels. You will be clicking and dragging the test tubes individually into the pH meter. Once the tubes lock into place, you will click **Measure pH**. An electrode will descend into the tube’s contents and take a pH reading.

6. Click and drag test tube #1 into the pH meter.

7. Click **Measure pH**.

8. Record the pH value in Chart 4 on page 110, then return the test tube to its slot on the incubator.

9. Repeat steps 6–8 for the remaining test tubes.

10. When all of the tubes have been analyzed, click **Record Data**.

11. Click **Tools** at the top of the screen and then **Print Data** if you wish to print out a hard copy of your data.

12. Dispose of the test tubes by dragging them individually to the test tube washer.

What did tube #1 show?

Why was tube #1 found to have a pH of 7?

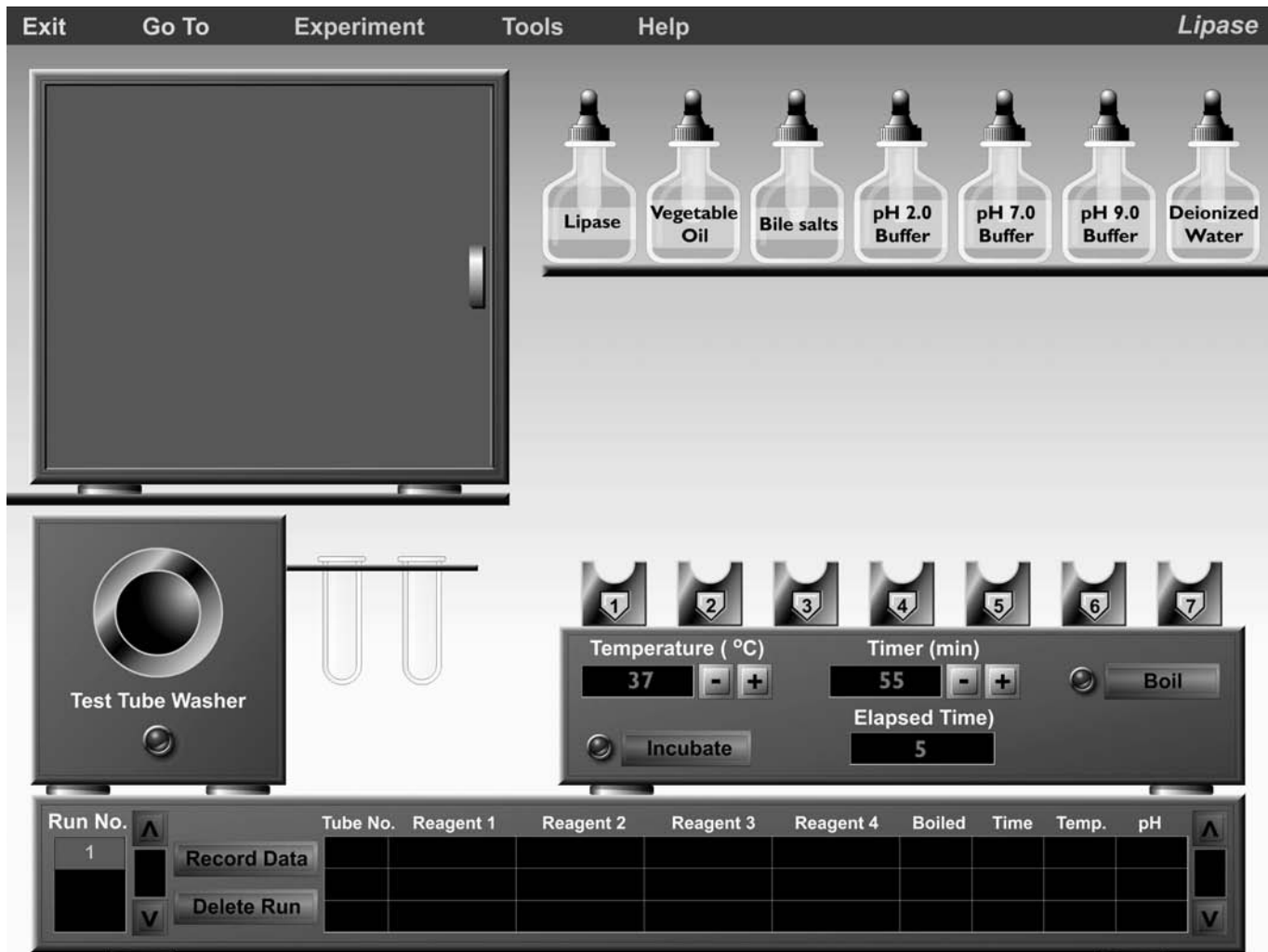


FIGURE 8.3 Opening screen of the Lipase experiment.

CHART 4		Results of Activity 4						
Tube No.	1	2	3	4	5	6	7	
Additives	lipase vegetable oil bile salts	lipase vegetable oil bile salts	lipase vegetable oil deionized water	lipase deionized water bile salts	deionized water vegetable oil bile salts	lipase vegetable oil bile salts	lipase vegetable oil bile salts	
	pH 7.0 buffer	pH 7.0 buffer	pH 7.0 buffer	pH 9.0 buffer	pH 7.0 buffer	pH 2.0 buffer	pH 9.0 buffer	
Incubation condition	boiled, then incubated 37°C	37°C	37°C	37°C	37°C	37°C	37°C	
pH								

What is the main difference between tubes #2 and #3?

What is the action of the substance in tube #2 that was not included in tube #3?

Can we determine if fat hydrolysis has occurred in tube 5?

Explain your answer. _____

What effect did the other buffers have on the digestive process?

What are the products of lipase digestion in tube #2?

In what tubes did you detect the presence of fatty acids?

Physical Processes of Digestion

Keep in mind that the chemical processes of enzyme activity are only part of the digestive process. Physical processes are also involved. Chewing, for example, mixes food with salivary mucus and amylase, reduces it to small, manageable particles and transforms it into a swallowable mass called a *bolus*. The tongue separates the bolus from the mass of food in the mouth, pressing it against the hard palate. The bolus then enters the pharynx, stimulating tactile receptors that initiate the swallowing reflex and propel the bolus through the esophagus. A wave of contraction called *peristalsis* then moves the bolus into the stomach, where the bolus is converted to *chyme*. Stomach muscles mix the chyme with gastric juices to fragment the food into still smaller particles; they also regulate the entry of chyme into the small intestine. Peristalsis continues in the small intestine, periodically interspersed by *segmentation*, in which the chyme is shuttled back and forth by the contraction and relaxation of the intestinal segments. Segmentation thoroughly mixes chyme with digestive enzymes, bile, and bicarbonate ions secreted by the pancreatic duct, and increases the efficiency of nutrient absorption into the blood.

Histology Review Supplement

For a review of digestive tissue, go to **Exercise H: Histology Atlas & Review** on the **PhysioEx website** to print out the **Digestive Tissue Review** worksheet.