Picture Perfect

As she drove back to the museum, Bryn considered the box and the tiny dress it contained. It had been worn by a child in a 19th-century portrait of a local family already owned by the museum. Discovered in a trunk in an unheated barn by descendants, the dress was in surprisingly good condition.

Once she arrived, Bryn went to the curators' workroom to give the dress to Rob, the museum's textile conservator. Seeing Rob working intently, she quietly knocked on the half-open door. He put down his tools and looked up.

"Rob," she said excitedly. "Here is the dress I told you about from the painting! The donor was about to have it cleaned, but I'm so glad he called here first."

"You're not kidding! It's easy to ruin old fabrics," Rob said as he accepted the box with the tissue-wrapped dress. After putting on gloves, he unwrapped the old dress carefully and laid it flat on a clean table to examine it. He saw that the cotton dress was slightly yellowed and there was a small, stiff stain near the neckline. He wondered if that spot might prove troublesome. "This is terrific, Bryn. I'll do my magic, and with luck these discolorations and spots should disappear."

Bryn laughed. She knew that Rob's work had nothing to do with magic or luck. As she left the workroom, Rob grabbed an *Object Description and Restoration* form and began to fill it out in pencil. Next he gently brushed the dress. Using a metal probe, he scraped the stain at the neckline and placed the sample on a microscope slide.

Rob examined the slide with the microscope, noticing several granules mixed in with a few longer fibers. He was not surprised to see long cellulose fibers, which he knew to be cotton. The granules, though, which were smooth and oval-shaped with a diameter of about 75 μm (micrometers), came from the stain itself. He added a drop of a weak, yellowish iodine solution to the slide. The granules turned dark blue. Under *Treatment Plan* he wrote "Neckline stain: use amylase cleaning solution"—an enzymatic solution specific for removing starch.

Figure 1.1 Museum textile conservators apply their knowledge of the structure and function of macromolecules to clean, restore, and preserve old fabrics such as this dress.

CASE ANALYSIS

1. **Recognize potential issues and major topics in the case.** What is this case about? Underline terms or phrases that seem to be important to understanding this case. Then list **three or four** biology-related topics or issues in the case.

2. **What specific questions do you have about these topics?** By yourself, or better yet, in a group, list what you already know about this case in the "What Do I Know?" column. List questions you would like to learn more about in the "What Do I Need to Know?" column.

What Do I Know?	What Do I Need to Know?

3. Put a check mark by **one to three** questions or issues in the "What Do I Need to Know?" list that you think are most important to explore.

4. **What kinds of references or resources would help you answer or explore these questions?** Identify two different resources and explain what information each resource is likely to give that will help you answer the question(s). Choose specific resources.

Core Investigations

I. Critical Reading

To complete this investigation, you should have already read Concepts 5.1–5.3 in Chapter 5. In Concept 8.4, you should also read the text under the headings "Substrate Specificity of Enzymes" and "Effects of Local Conditions on Enzyme Activity." Then answer the following questions.

1. In the case narrative, Rob learned that the stain near the neckline of the dress contained starch. What specific types of macromolecule are starch and cellulose?

2. What monomer is found in starch and cellulose?

3. Contrast the structure and function of starch with those of cellulose in plant cells.

4. What is an enzyme?

5. To remove the stain from the dress, Rob treated the stain with a cleaner containing the hydrolytic enzyme *amylase*. Explain what happens to starch at the molecular level when it is acted upon by amylase. You may wish to sketch the structure of starch to show how this enzyme works (see Figure 5.7 in your text).

6. Under the right conditions, amylase breaks down amylose efficiently; however, the enzyme is not very effective in breaking down amylopectin. Examine Figure 5.6 and read the related text in your textbook. Use your observations to propose a hypothesis for why amylase breaks down amylose much more effectively than amylopectin.

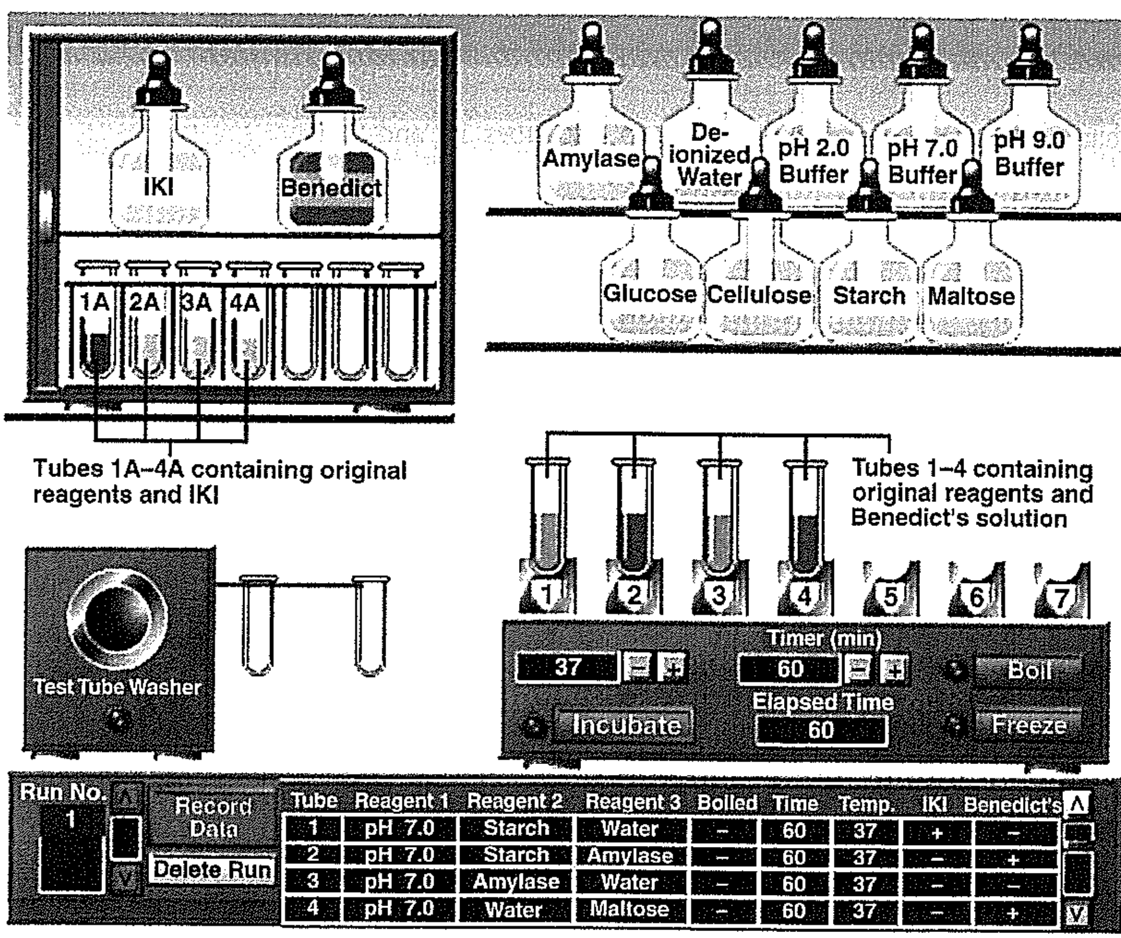
7. Explain why Rob did not have to worry that the amylase cleaning solution would damage the dress.

II. Analyze and Design an Experiment

To further investigate starch and its components, first you will analyze an experiment. Then you will design your own. The experiment you will analyze was performed using the software in the *Chapter 41 Investigation: What Role Does Amylase Play in Digestion?* found on the Campbell website (http://www.masteringbio.com) and CD-ROM. However, you can complete the exercise with the information provided in this workbook.

A. Analyze an Experiment. In the following controlled experiment, we used both iodine solution (IKI) and Benedict's solution as indicators to test the effect of amylase on starch. As you may recall, Rob used the indicator iodine to test the dress stain for the presence of starch.

The Experiment: Four test tubes were set up. To find out which substances were placed in each tube, see the table in the bottom section of Figure 1.2. The tubes were then incubated at 37°C for 60 minutes (none were boiled). Half of the contents in tubes 1–4 were poured into tubes 1A–4A. The contents of tubes 1A–4A were tested with IKI. The remaining contents in tubes 1–4 were tested with Benedict's solution. The next set of questions asks you to analyze the results of both tests.



Tube	Reagent 1	Reagent 2	Reagent 3	Boiled	Time	Temp.	IKI	Benedict's
1	pH 7.0	Starch	Water	–	60	37	+	–
2	pH 7.0	Starch	Amylase	–	60	37	–	+
3	pH 7.0	Amylase	Water	–	60	37	–	–
4	pH 7.0	Water	Maltose	–	60	37	–	+

Figure 1.2 Experimental setup and results.

1. Review Figure 1.2 and note which of the reagents were used in each of the four test tubes. In Table 1.1, check off the reagents found in each tube.

Table 1.1 Test Tube Contents

Reagent	Test Tube			
	1	2	3	4
Starch				
Amylase				
Buffer pH 7.0				
Maltose				
Water				

2. Note the test tube results for the use of IKI. The color change in the contents of each test tube is also shown in the test-tube rack at the upper left corner of the figure. A dark shade indicates a positive iodine reaction (the actual color is dark blue) and a light shade indicates a negative reaction (the actual color is yellow). Because Rob used iodine in this case, you know that iodine is a test for starch. Why, then, was the iodine test negative for test tube 2A?

3. What is the purpose of adding iodine to test tubes 1A and 3A?

4. Now examine the results for the Benedict's solution test. Color changes are shown in the rack containing tubes 1–4 at the middle right. A dark shade indicates a positive test (the actual color is reddish brown). A light shade indicates a negative test (the actual color is blue). Do you think Benedict's solution is a test for starch, amylase, or maltose? Explain.

B. Design Your Own Experiment

1. Using *either* the iodine test or the Benedict's test, design an experiment to examine other factors in the action of amylase on starch. Your experiment should test only *one* of the following variables: pH, incubation temperature, incubation time, boiling, or freezing.

a. What question will you investigate in your experiment?

b. Restate the question as a hypothesis (see Chapter 1 in your textbook for an explanation of forming hypotheses):

If ____,

then ____.

2. In Table 1.2, describe your experimental treatment in test tube 1. Although it is likely that you will have more than one control tube, describe just one of your controls for test tube 2.

Table 1.2 Test Tube Contents and Conditions

Reagents	**Test Tube 1 (experimental)**	**Test Tube 2 (control)**
Starch		
Amylase		
pH		
Experimental conditions		
Incubation time		
Incubation temperature		
Boiling		
Freezing		

3. In Table 1.3, indicate the results you would expect if your hypothesis were supported (use "+" and "−" for the test indicator that you chose).

Table 1.3 Predicted Results, Supporting Hypothesis

Tests	**Test Tube 1**	**Test Tube 2**
Benedict's		
IKI		

4. In Table 1.4, indicate the results you would expect if your hypothesis were *not* supported (use "+" and "−" for the test indicator that you chose).

Table 1.4 Predicted Results, Not Supporting Hypothesis

Tests	**Test Tube 1**	**Test Tube 2**
Benedict's		
IKI		

5. *Optional.* Conduct the experiment you designed using the software provided in the *Chapter 41 Investigation: What Role Does Amylase Play in Digestion?* found on the Campbell website (http://www.masteringbio.com) or CD-ROM. Turn in a screen capture of the table showing your results. *Note:* Experiments involving IKI tests of cellulose will not give the correct results due to a bug in the software.

III. Off the Wall: Starch Degradation Investigation

Hildy planned to surprise her parents by remodeling their living room while they were away for the weekend. First she had to remove the wallpaper so that she could paint. When she started scraping at the edge of the dry wallpaper, only a few small pieces came off. "What's up with this wallpaper?" Hildy asked herself. "It's just not coming off!"

Hildy got a spray bottle and filled it with warm water. She sprayed the walls to moisten large areas. After several minutes, she scraped at the wallpaper again. Larger pieces came off this time, but big patches of hardened paste remained. Hildy couldn't spend the whole weekend scraping! She rummaged around the house and found some alcohol and some vinegar.

Unsure of what these substances would do to the walls, she also went out and bought two different types of commercial wallpaper remover. "I wonder which of these will work the best?" she thought.

To test which one would work best, she chose a section of the wall behind the couch and applied the five substances to a 10-cm^2 section of the wall. She labeled each patch to remember which substance had been applied to each square. After 20 minutes, she noted how much wallpaper she could remove with one scrape from each patch. See the results of her experiment in Figure 1.3.

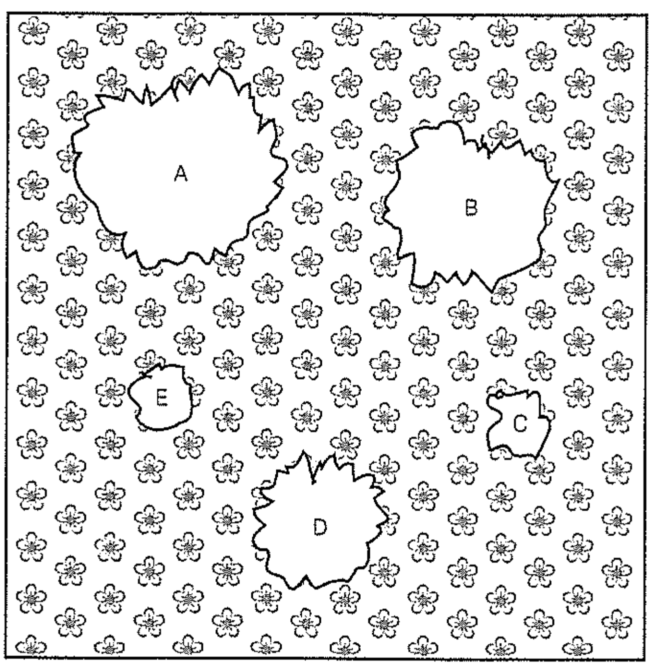


Figure 1.3 A section of Hildy's parents' living room wall after her experiment. The table on the next page is a key containing her results.

Label on Wallpaper	Substance	Approximate % of Wallpaper and Paste Removed
A	remover with 0.5% amylase	100
B	remover with 0.1% amylase	75
C	rubbing alcohol	10
D	vinegar	50
E	water	10

1. Which substance worked best? What does this tell you about the composition of wallpaper paste?

2. Describe how the most effective substance worked to remove the paste.

3. Considering that vinegar is an acid, explain the results seen with the vinegar.

4. Why was it important that Hildy also test the effect of water alone on the wallpaper paste?

Additional Investigations

IV. Structure and Function of Starches

A. Kinds of Starch. Starches are a significant part of the typical human diet, making up 40–80% of total energy intake. Some plants store more starch than others. Humans have discovered many varieties of starchy plants that satisfy our hunger and taste buds, such as corn, cassava, and potatoes, originally from South America; sweet potatoes and yams, from tropical Africa and South America; chickpeas, from Turkey; plantains, originally from India; rice, originally from Asia; soybeans, originally from China; and wheat, from the Middle East.

Plants store starch as highly condensed granules that do not dissolve easily in water. The composition and size of these granules vary in different types of plants.

1. Contrast the microscopic starch granules of corn with those of potato, shown in Figure 1.4.

(a) Starch granules in corn (5–25 μm) (b) Potato starch (15–100 μm)

Figure 1.4 Note the variations in the size and shape of starch granules.

2. Now that you have learned more about the different types of starch granules, can you infer the type of granules that Rob scraped from the old dress? Explain your response.

B. Using Starches in Food: Understanding Structure for Commercial Application. Although the enzymes in our digestive system are capable of breaking apart starch granules, cooking starchy foods causes the starches to gelatinize, which enhances texture and taste and improves digestion. *Gelatinization* is the process in which granules of starch swell, break up, and disperse in water. Suspensions of various thicknesses are formed during this process.

Figure 1.5 on the next page shows a cornstarch granule before and after gelatinization. (Cornstarch is often used as a thickening agent in food products such as gravies and sauces.) Starch granules have complex structures. The granule surface consists of many amylopectin and some amylose molecules associating tightly with each other due to hydrogen bonding. Water does not easily penetrate the granule. Tiny channels lead from the surface into an amorphous center where less tightly bound amylose and amylopectin molecules are found.

When starch granules are immersed in water, two things happen. Water moves slowly through the channels and forms hydrogen bonds with the amylose and amylopectin components in the center of the granules. At the same time, hydrogen bonding among the amylose and amylopectin molecules on adjacent granules causes clumping. Stirring the suspension prevents the granules from forming dense clumps. If understirred, the cornstarch mixture will be lumpy.

When exposed to heat, water molecules move more rapidly. The rapid movement allows more water molecules to enter the granules, causing the granules in the suspension to swell. The cornstarch and water mixture noticeably thickens (increases in viscosity). Because amylose molecules are unbranched, they can easily move through the channels and will leach out of the granules more quickly than amylopectin. If the gel sits and cools at this stage, the amylose molecules will begin to realign by hydrogen bonding, causing the granules to adhere to each other and to the container. The cornstarch may thicken unevenly and the resulting mixture will be difficult to pour.

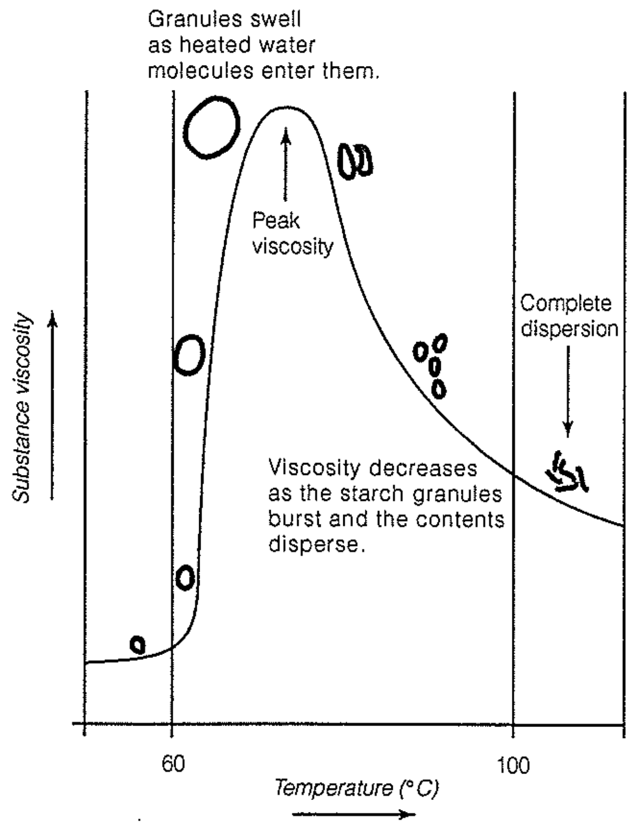


Figure 1.5 Gelatinization and disruption of starch molecules.

On the other hand, continued heating of the gelatinized starch transfers more energy to the water molecules, allowing them to further destabilize hydrogen bonds between starch molecules. The granules continue to swell, and more starch molecules leak into the surrounding liquid. Heating past the boiling point causes swollen granules to break into fragments and release all of the starch molecules into the water. At this point, the mixture thins (decreases in viscosity). Stirring the mixture will hasten the thinning process, leading to a runny cornstarch mixture.

Investigation: What Went Wrong?

Gravy and mashed potatoes are two foods prepared in many U.S. homes, but they are tricky to make successfully. Examine the recipes on the next page for gravy and mashed potatoes and answer the following questions using your knowledge of the gelatinization process. (*Hint:* The secret to making gravy and mashed potatoes is maintaining an even distribution of granular structure without fragmenting the individual granules.)

Turkey Gravy	Mashed Potatoes
1. In a large saucepan, over medium heat, bring 1 cup of turkey broth and pan juices to a boil. 2. Meanwhile, blend until smooth 2 tablespoons of cornstarch in 1 cup of cold water. 3. Slowly add the cornstarch mixture to the boiling broth. 4. Stir intermittently until the gravy thickens. 5. Season to taste with salt and pepper. 6. Remove from heat and serve immediately.	1. Place a large pot of cold water on the stove. 2. Peel each potato, cut into cubes of about 3/4-inch square, and put in the pot. 3. Do not allow the water to boil too rapidly; check for doneness after 15 minutes. 4. Mash the potatoes while they are hot. Do not overmash. Never use a food processor. 5. Mix in butter and milk. Do not let potatoes cool.

1. As you begin to prepare turkey gravy, you carefully blend 2 tablespoons of cornstarch into a cup of cold water. You add the mixture to the turkey broth, but then you forget to stir it. Your gravy turns out lumpy. How did the mistake ruin the gravy?

2. To make mashed potatoes, you boil the potatoes for 25 minutes. The potato chunks begin to disintegrate as you drain them. When you add the butter and milk, the potatoes are thin and gluey—similar to wallpaper paste before it dries. What went wrong?

C. Structural Properties of Native and Modified Starches in Commercial Products. Starch has a number of properties that make it useful to manufacturers of prepared foods and other commercial products such as glues. Cornstarch products, such as corn syrup, are among the most common ingredients listed on the food labels of cookies, puddings, frozen dinners, and crackers.

Naturally occurring starches (native starches) may be used in dry form as ingredients for foods (about 75% of wheat flour is starch) or as dry lubricants (baby powder), but most are added to water to create gels and solutions. Two widely used types of native cornstarch, *dent* and *waxy,* vary in their amylose content, which makes them useful for different purposes.

Dent cornstarch comes from the most frequently planted type of corn in the United States. Dent cornstarch usually contains about 80% amylopectin and 20% amylose. Starch products made with dent corn tend to adhere to surfaces and form more rigid layers as they are cooked or allowed to dry. For example, dent cornstarch is used in the production of wallpaper paste. Amylose causes the wallpaper to stick to the wall through hydrogen bonding with cellulose and then to stiffen as it dries. The harder outer coating of jelly beans is also made from dent starch.

Waxy cornstarch is produced by a type of corn plant that does not produce amylose. Waxy starch consists entirely of amylopectin molecules. When this cornstarch is dissolved in a solution, it tends to be more stable than the dent cornstarch. The resulting product pours easily. For example, hot chocolate mixes contain waxy cornstarch.

Manufacturers often chemically modify native cornstarch to form additional bonds that cross-link amylose molecules or cross-link amylose and amylopectin molecules. These modified starches have different chemical properties than the native starches.

- Cross-linked waxy starches like Consista® and Rezista® absorb water but retain their granular structure, producing more stable mixtures with higher viscosity than that found in native starches. Products requiring a thicker consistency, such as gravy in canned stew, often contain modified waxy starch.
- Amylomaize, another modified starch, contains 70% amylose and 30% amylopectin. Manufacturers use amylomaize to make inexpensive and biodegradable packaging foam with good cushioning and resiliency properties. For starch to act like polystyrene (a plastic), its polymer molecules have to align closely through hydrogen bonds. Linear molecules perform better in this way than branched molecules; therefore, the high amylose content of amylomaize makes it work well.

Read the following product description and determine which starch would be the best choice for a manufacturer. (*Note:* The cost of dent starch is low, waxy starch is more expensive, and chemically modified waxy starches are the most expensive. Although cost is always an important factor in manufacturing decisions, for this exercise consider only the characteristics of the different types of starch.)

A. Dent starch
B. Waxy starch
C. Modified waxy starch
D. Amylomaize

1. **Instant cheesecake mix.** Manufacturers need a starch that will maintain a creamy consistency and will neither liquefy nor harden at room temperature. Explain your choice.

2. **Soups.** Manufacturers need a starch that allows their product to be pourable but does not thicken too much as it cools. Explain your choice.

3. **Batter and breading.** Manufacturers need a starch that will adhere to chicken and then become crunchy as the chicken is cooked. Explain your choice.

V. Open-Ended Investigations

Why is starch used in papermaking? Consider the structure of starch molecules in your answer.

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