24.3 Amino Acids and Their Polymers

Connecting to Your World Many people are lactose intolerant, which means that they cannot digest milk or products containing milk. These people cannot digest milk products because their bodies do not produce enough of the enzyme lactase to digest lactose, the sugar found in milk. The undigested lactose causes bloating and stomach upset. Some people with lactose intolerance can enjoy milk products if they take a pill containing lactase before eating. In this section, you will learn what enzymes are and what function they serve in the body.

Guide for Reading

Key Concepts

- What is the general structure of an amino acid?
- Which functional groups are always involved in amide bonds between amino acids?
- What determines the differences in the chemical and physiological properties of peptides and proteins?
- How do enzymes affect the rates of reactions in living things?

Vocabulary

amino acid
peptide
peptide bond
protein
enzymes
substrates
active site

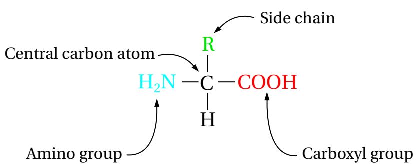
Reading Strategy

Outlining As you read the section, make an outline of the red and blue heads. Under each head, write one or two sentences summarizing what you learned from that part of the section.

Amino Acids

Many biological compounds contain nitrogen in addition to carbon, oxygen, and hydrogen. Some of the most important nitrogen-containing molecules in organisms are amino acids. In fact, the polymers of amino acids, which you will also learn about, make up more than one half of the dry weight of your body.

An **amino acid** is any compound that contains an amino group (—NH_2) and a carboxyl group (—COOH) in the same molecule. For chemists and biochemists, however, the term is usually reserved for the 20 common amino acids that are formed and used by living organisms. **Amino acids have a skeleton that consists of a carboxyl group and an amino group, both of which are covalently bonded to a central carbon atom. The remaining two groups on the central carbon atom are hydrogen and an R group that constitutes the amino acid side chain.**



The chemical nature of the side-chain group accounts for the differences in properties among the 20 amino acids. In some amino acids, the side chains are nonpolar aliphatic or aromatic hydrocarbons. In other amino acids, the side chains are neutral but polar. In still others, the side chains are acidic or basic.

Because the central carbon of amino acids is asymmetric, these compounds can exist as optical isomers. As you may recall from Section 22.3, optical isomers may be right- or left-handed. Nearly all the amino acids found in nature are of the left-handed, or L, form.

24.3

1 FOCUS

Objectives

24.3.1 Diagram the structure of an amino acid.
24.3.2 Describe how peptide bonds form and **identify** what determines the properties of peptides and proteins.
24.3.3 Describe how enzymes affect biochemical reactions.

Guide for Reading

Build Vocabulary L2

Graphic Organizers Have students use a Venn diagram to compare peptides to proteins. They should include the vocabulary for the section and ask themselves, What do peptides and proteins have in common? What is unique to each?

Reading Strategy L2

Relate Text and Visuals Have students skim this section, paying attention to the figures. Ask, **What are some of the three-dimensional shapes formed by peptide molecules?** *(straight chains, helical chains, and pleated sheets)*

2 INSTRUCT

Connecting to Your World

Point out that the prevalence of lactose intolerance in a population depends on ethnic origins. In the United States it is least prevalent in people of northern European descent and most prevalent in Asian Americans. Ask, **What does the enzyme lactase do for people?** *(helps them digest milk)*

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 24.3
- **Core Teaching Resources,** Section 24.3
- **Transparencies,** T275–T278

Technology

- **Interactive Textbook with ChemASAP,** Assessment 24.3
- **Go Online,** Section 24.3

Amino Acids

Discuss L2

Discuss how to calculate the number of possible arrangements of amino acids in proteins. Ask, **How many different ways can eight different amino acids be arranged to form a peptide?** *($8! = 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1 = 40{,}320$)* Ask, **How many combinations are possible for a peptide made of 10 different amino acids?** *($10! = 3{,}628{,}800$)* Point out to students that an average protein usually contains more than 100 amino acids.

Peptides

TEACHER Demo

Peptide Models L2

Purpose Students observe how amino acids link through amide bonds to form peptides.

Procedure Create models of peptides by linking amino acids with amide bonds. Point out that peptide formation is another example of a condensation polymerization. Ask students to describe how continuing the polymerization process produces protein molecules.

Expected Outcome Students should be able to describe peptide formation by manipulating the models.

Proteins

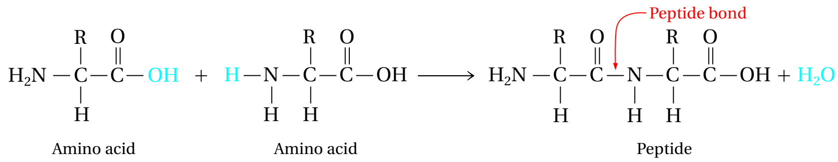
Discuss L2

Point out that the types of amino acids in proteins have a large influence on the physical and chemical properties of the protein. The twenty common amino acids can be grouped into two major categories: polar or nonpolar. The ratio of polar to nonpolar amino acids profoundly affects the shape of a protein. Discuss why this should be. When a protein folds, nonpolar amino acids are sequestered to the interior of the protein, away from the aqueous environment. Polar amino acid residues often predominate on the surface of proteins.

Table 24.1 gives the names of the amino acids with their three-letter abbreviations. Examine the abbreviations. You will use them as shortcuts when you read or write about protein structure.

Peptides

A **peptide** is any combination of amino acids in which the amino group of one amino acid is united with the carboxyl group of another amino acid. The amide bond between the carboxyl group of one amino acid and the nitrogen in the amino group of the next amino acid in the peptide chain is called a **peptide bond.**



The amide bonds between amino acids always involve the central amino and central carboxyl groups. The side chains are not involved in the bonding.

Note that a free amino group remains at one end of the resulting peptide. The convention is to write the formula of the peptide so that this free amino group is at the left end. There is also a free carboxyl group, which appears at the right end.

More amino acids may be added to the peptide in the same fashion to form long chains by condensation polymerization. The order in which the amino acids of a peptide molecule are linked is called the amino acid sequence of that molecule. The amino acid sequence of a peptide is conveniently expressed using the three-letter abbreviations for the amino acids. For example, Asp—Glu—Gly represents a peptide containing three amino acids. This tripeptide contains aspartic acid, glutamic acid, and glycine, in that order, with the free amino group assumed to be on the left end (on the Asp) and the free carboxyl group on the right end (on the Gly). Note that Asp—Glu—Gly is a different peptide from Gly—Glu—Asp because the order of amino acids is reversed, and thus the free amino group and free carboxyl group are on different amino acids.

Checkpoint ***By what process can amino acids be added to peptides to form long chains?***

Table 24.1 Abbreviations for Amino Acids

Amino acid	Abbreviation
Alanine	Ala
Arginine	Arg
Asparagine	Asn
Aspartic acid	Asp
Cysteine	Cys
Glutamine	Gln
Glutamic acid	Glu
Glycine	Gly
Histidine	His
Isoleucine	Ile
Leucine	Leu
Lysine	Lys
Methionine	Met
Phenylalanine	Phe
Proline	Pro
Serine	Ser
Threonine	Thr
Tryptophan	Trp
Tyrosine	Tyr
Valine	Val

Proteins

In theory, the process of adding amino acids to a peptide chain may continue indefinitely. Any peptide with more than ten amino acids is called a polypeptide. A peptide with more than about 100 amino acids is called a **protein.** On average, a molecule of 100 amino acids has a molar mass of about 10,000 amu. Proteins are an important class of biomolecules. Your skin, hair, nails, muscles, and the hemoglobin molecules in your blood are made of protein. Proteins are needed for almost all chemical reactions that take place in the body.

Facts and Figures

Ethnobiologists

Often exploring the remotest jungles and forests, ethnobiologists search for information about plants, fungi, and even insects that people use as medicine. These scientists carefully interview local specialists, who administer or use the remedies; collect samples of the remedies, and send these samples to laboratories for analysis of their chemical components. Ethnobiologists carry out an important task—fewer than 3% of the flowering plants on Earth have been examined for medicinal value, but about 40% of medicines in use today come from plant sources.

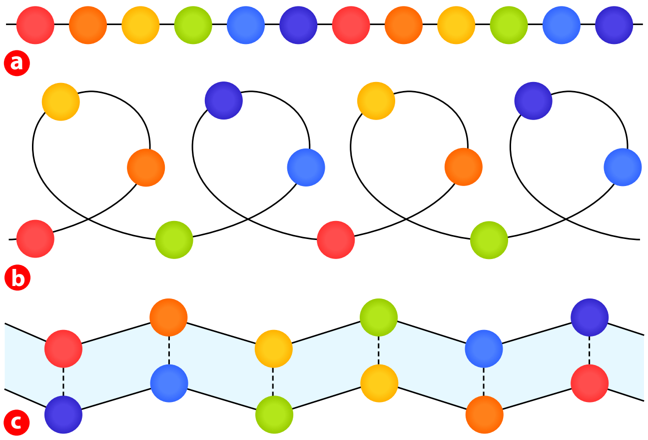


Figure 24.6 Peptides form three-dimensional shapes. (a) This is a representation of amino acids in a peptide chain. (b) The chain may coil into a helix. (c) Two peptide chains may become arranged in a pleated, sheet-like structure.
Applying Concepts ***What types of bonds determine the three-dimensional shape of a protein?***

Differences in the chemical and physiological properties of peptides and proteins result from differences in the amino acid sequence. 20 amino acids can be linked in an enormous number of ways in a protein molecule. As many as 20^{100} amino acid sequences are possible for a protein of 100 amino acids containing a combination of the 20 different amino acids.

Protein molecules are folded into relatively stable three-dimensional shapes. Figure 24.6a represents a long peptide chain of a protein. Figure 24.6b shows how sections of peptide chain may coil into a regular spiral, known as a helix. Peptide chains may also be arranged side by side to form a pleated sheet, as shown in Figure 24.6c. Irregular folding of the chains also can occur. The three-dimensional shape of a protein is determined by interactions among the amino acids in its peptide chains. Protein shape is partly maintained by hydrogen bonds between adjacent folded chains. Covalent bonds also form between sulfur atoms of cysteine side chains that are folded near each other. In that way, separate polypeptide chains may be joined into a single protein. Figure 24.7 traces the shape of myoglobin, a protein that stores oxygen in muscle cells. As you can see, the peptide chains of most of the myoglobin molecule are twisted into helixes.

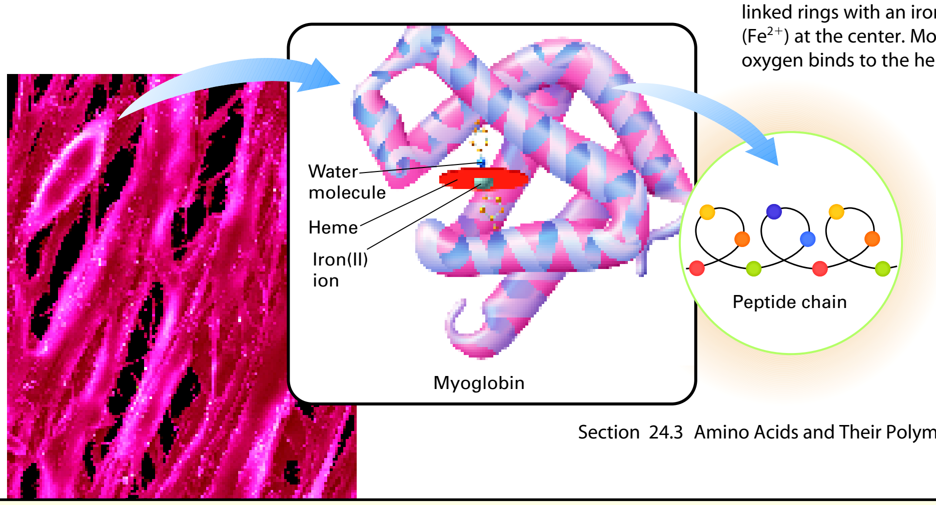


Figure 24.7 The three-dimensional structure of myoglobin, the oxygen storage protein of this muscle tissue, is shown here. Most of the peptide chain of myoglobin is wound into helixes. Myoglobin also contains a nonprotein structure called heme. The heme group is shown as a disk in the myoglobin structure. Heme contains four linked rings with an iron(II) ion (Fe^{2+}) at the center. Molecular oxygen binds to the heme iron.

TEACHER Demo

Protein in Hard Tissue L2

Purpose Students learn that some proteins play structural roles in hard tissue.

Materials thigh bone from cooked poultry, 1*M* HCl, beaker

Procedure Students may be surprised to learn that protein is a major structural constituent of bone. Illustrate this fact by soaking a thigh bone from cooked poultry in 1*M* HCl overnight. The next day, rinse the bone with water.

Expected Outcome Upon visual inspection it may seem as if no reaction has occurred at all; demonstrate that the bone can be bent and twisted quite easily. Point out that the mineral salts of the bone were dissolved in the acid. The acid-insoluble portion remaining consists of a special protein called collagen. Ask **What possible roles does collagen have in the formation and maintenance of healthy bone tissue?** *(It provides a framework for the deposition of calcium phosphate, the mineral that makes up bone, and for the growth of bone marrow cells.)*

Differentiated Instruction

Gifted and Talented L3

Scientists have long sought a reliable, general method for predicting the three-dimensional shape of any protein based on its amino acid sequence. Because a protein's shape is so closely associated with its substrate binding properties, a code for predicting protein structure would allow scientists to design new proteins and modify existing ones for a variety of purposes.

Have students find out how the amino acid sequence of a protein dictates its secondary and tertiary structure. Ask them to draw a simple protein (or part of one) that shows some of the bonds affecting its shape.

Answers to...

Figure 24.6 Hydrogen bonds

Checkpoint condensation polymerization

Enzymes

Use Visuals L1

Figure 24.8 Compare the binding of a substrate and an enzyme to the way in which a key fits into a lock. Ask, **How does the enzyme exclude all but the correct substrate?** *(The substrate has a matching, or complementary, shape.)* **What would happen to the system if you heated it until the enzyme shape changed?** *(The substrate would no longer fit.)*

TEACHER Demo

Enzymes L2

Purpose Students observe that enzymes speed up chemical reactions.

Materials Lactaid, dropper, water, 2 cartons of fresh milk, spoons or small cups

Procedure Treat one container of milk with Lactaid and one with an equal number of water dops. Store the milk cartons in the refrigerator for one to two days. Then have student volunteers do a comparative test.

Expected Outcome The container with added lactase should taste sour; the other container should still be fresh.

Go Online NSTA SCiLINKS

Download a worksheet on **Proteins/ Enzymes** for students to complete, and find additional teacher support from NSTA SciLinks.

Relate L2

Coenzymes are often vitamins; for example, B vitamins help release energy from foods. Lack of B vitamins usually produces malnourishment of some kind, since food can't be digested properly without them. Niacin and B_6 deficiencies, for example, produce skin and nervous system disorders, such as headaches, depression, and memory loss.

Go Online NSTA SCiLINKS

For: Links on Proteins/ Enzymes
Visit: www.SciLinks.org
Web Code: cdn-1243

Enzymes

Enzymes are proteins that act as biological catalysts. **Enzymes increase the rates of chemical reactions in living things.** In 1926, the American chemist James B. Sumner reported the first isolation and crystallization of an enzyme. The enzyme he isolated was urease, which hydrolyzes urea, a constituent of urine, into ammonia and carbon dioxide. The strong ammonia smell of wet diapers that are allowed to stand for a long time is the result of the action of bacteria that contain this enzyme. The reaction is shown below.

$$\underset{\text{Urea}}{H_2N-\overset{\overset{\displaystyle O}{\|}}{C}-NH_2(aq)} + \underset{\text{Water}}{H_2O(l)} \xrightarrow{\text{urease}} \underset{\text{Ammonia}}{2NH_3(g)} + \underset{\text{Carbon dioxide}}{CO_2(g)}$$

Since the discovery of urease, thousands of enzymes have been isolated and structurally characterized as proteins.

In addition to being able to promote reactions, enzymes have two other properties of true catalysts. First, they are unchanged by the reaction they catalyze. Second, they do not change the normal equilibrium position of a chemical system. The same amount of product is eventually formed whether or not an enzyme is present. Few reactions in cells ever reach equilibrium, however. The products tend to convert rapidly to another substance in a subsequent enzyme-catalyzed reaction. According to Le Châtelier's principle, such removal of a product pulls the reaction toward completion.

How Enzymes Work Enzymes catalyze most of the chemical changes that occur in the cell. **Substrates** are the molecules on which an enzyme acts. In a typical enzymatic reaction, diagrammed in Figure 24.8, the substrate interacts with side chains of the amino acids on the enzyme. These interactions cause the making and breaking of bonds. A substrate molecule must make contact with and bind to an enzyme molecule before the substrate can be transformed into product. The place on an enzyme where a substrate binds is called the **active site.** An active site is usually a pocket or crevice formed by folds in the peptide chains of the enzyme protein. The peptide chain of an enzyme is folded in a unique way to accommodate the substrate at the active site. The diagram in Figure 24.9 shows this folding for an enzyme called HIV protease, which is produced by the virus that causes AIDS.

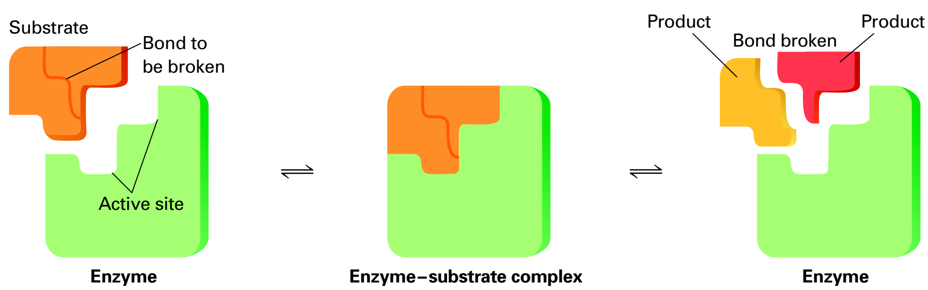
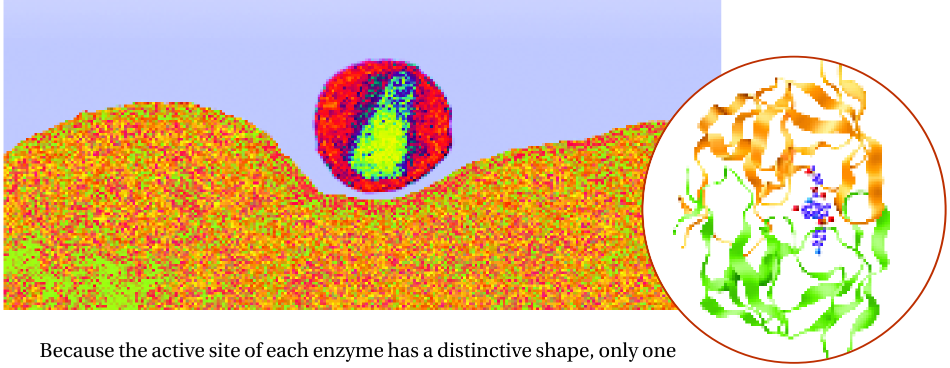


Figure 24.8 A substrate fits into a distinctively shaped active site on an enzyme. Bond-breaking occurs at the active site to produce the products of the reaction. **Predicting** ***What would happen if access to the active site were blocked by another molecule?***

Differentiated Instruction

Less Proficient Readers L1

Many laundry detergents contain enzymes that are supposed to help remove stains. Ask students to read the labels of a number of laundry detergents and find out if enzymes are listed among the ingredients. Ask them to hypothesize how enzymes improve the cleaning performance of a detergent.



Because the active site of each enzyme has a distinctive shape, only one specific substrate molecule can fit into the enzyme, in the same way that only one key will fit into a certain lock. Each enzyme catalyzes only one chemical reaction, with only one substrate. An enzyme-substrate complex is formed when an enzyme molecule and a substrate molecule are joined.

To see the efficiency of enzymes, consider an enzyme called carbonic anhydrase. It catalyzes the reversible breakdown of carbonic acid to carbon dioxide and water. One molecule of carbonic anhydrase can catalyze the breakdown of 36 million molecules of carbonic acid in one minute!

$$\underset{\text{Carbonic acid}}{H_2CO_3(aq)} \xrightleftharpoons{\text{carbonic anhydrase}} \underset{\text{Carbon dioxide}}{CO_2(g)} + \underset{\text{Water}}{H_2O(l)}$$

Figure 24.9 This color-enhanced scanning electron micrograph shows HIV (red particle) infecting a human white blood cell (orange). The diagram models the enzyme HIV protease. The green and yellow ribbons trace the two peptide chains of the enzyme. A substrate molecule (purple) is embedded in the active site formed between the two peptide chains.

Coenzymes Some enzymes can directly catalyze the transformation of biological substrates without assistance from other substances. Other enzymes need nonprotein coenzymes, also called cofactors, to assist the transformation. Coenzymes are metal ions or small organic molecules that must be present for an enzyme-catalyzed reaction to occur. Many water-soluble vitamins, such as B vitamins, are coenzymes. Metal ions that act as coenzymes include the cations of magnesium, potassium, iron, and zinc. The enzyme catalase includes an iron(III) ion in its structure. Catalase catalyzes the breakdown of hydrogen peroxide to water and oxygen.

$$2H_2O_2(aq) \xrightarrow{\text{catalase}} 2H_2O(l) + O_2(g)$$

24.3 Section Assessment

15. **Key Concept** What are the four groups that surround the central carbon atom in an amino acid?
16. **Key Concept** Which functional groups are always involved in amide bonds?
17. **Key Concept** What determines the differences in the properties of peptides and proteins?
18. **Key Concept** How do enzymes affect the reaction rates in living things?
19. What is meant by the amino acid sequence of a protein?
20. Describe three properties of enzymes.

Connecting Concepts

Reversible Reactions Reread Section 18.2 on reversible reactions and equilibrium. Use Le Châtelier's principle to explain why few reactions in cells ever reach equilibrium.

Interactive Textbook

Assessment 24.3 Test yourself on the concepts in Section 24.3.

with ChemASAP

3 ASSESS

Evaluate Understanding L2

Have students sketch the general structure of a tripeptide—such as Gly-Val-Trp—using letter abbreviations in place of the R group. Ask them to label the peptide bonds and the carboxyl and amino ends. Ask, **Which element do proteins contain that carbohydrates do not?** *(nitrogen)* **What is an enzyme?** *(Enzymes are proteins that function as biological catalysts.)* Have students describe one enzyme discussed and its function. *(One example is urease, which catalyzes the hydrolysis of urea.)*

Reteach L1

Use dryer duct tubing or slinky toys to help illustrate the secondary and tertiary structure of proteins. Point out that many of the amino acids in an enzyme are not directly involved in catalysis because they lie far from the active site. However, they do participate in intermolecular forces, which maintain the folded shape of the protein, a prerequisite for its biological activity.

Connecting Concepts

In cellular reactions, the products tend to convert rapidly to another substance in a subsequent enzyme-catalyzed reaction. According to Le Châtelier's principle, if the products of a reaction mixture are continually removed, the reaction will tend to go to completion rather than establish equilibrium.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 24.3.

with ChemASAP

Section 24.3 Assessment

15. amino, carboxyl, R, and hydrogen
16. The amino group of one amino acid combines with the carboxylic acid group of another to form an amide linkage
17. differences in the amino acid sequence
18. Enzymes speed up the rate of reaction but do not affect the position of equilibrium.
19. the order of amino acids in the protein molecule
20. catalysts (they remain unchanged in a reaction); usually proteins; specific to the reactions they catalyze

Answers to...

Figure 24.8 Transformation of the substrate into product could not occur.

Small-Scale LAB

The Egg: A Biochemical Storehouse L2

Objective Students examine the physical and chemical properties of a chicken egg.

Skills Focus Measuring, calculating, designing experiments

Prep Time 20 minutes

Materials Chicken egg, metric ruler, mass balance, NaOH, $CuSO_4$, HCl

Advance Prep Make up reagents as follows:

Solution	Preparation
0.5*M* NaOH	20.0 g in 1.0 L
0.2*M* $CuSO_4$	12.5 g $CuSO_4 \cdot 5H_2O$ in 250 mL
1.0*M* HCl	82 mL of 12*M* in 1.0 L

Class Time 20 minutes

Safety Always add acid to water carefully and slowly!

Teaching Tips

- For each class, obtain at least a dozen eggs of two or three different sizes: medium, large, and extra large. Some markets also sell small or jumbo eggs. This will allow students to obtain data from classmates about eggs that are a different size than their own.
- Have students write their names on their eggs so they can identify them the next day.
- Store some eggs in a refrigerator and some at room temperature if students are going to do activities 1, 2, and 8 in the You're the Chemist section.

Expected Outcome

Sample data: length = 5.90 cm; width = 4.55 cm; mass = 62.42 g.

Analyze

1. shape index = $\frac{4.55 \text{ cm}}{5.90 \text{ cm} \times 100\%}$ =77.1

2. $V = (0.5236)(5.90 \text{ cm})(4.55 \text{ cm})^2$
$= 64.0 \text{ cm}^3$
$M = (0.5632)(5.90 \text{ cm})(4.55 \text{ cm})^2$
$= 68.8 \text{ cm}^3$
$A = 3.138[(5.90 \text{ cm})(4.55 \text{ cm})^2]^{2/3}$
$= 77.3 \text{ cm}^3$

3. The measured mass of 62.42 g is less than the calculated mass of 68.8 g by 6.4 g. The egg may have lost water.

4. $d = \frac{62.42 \text{ g}}{64.0 \text{ cm}^3} = 0.975 \text{ g/cm}^3$
This is less than the density of a freshly laid egg.

You're the Chemist

1. Measure the mass each day for two or three days. Eggs lose 0.2 to 0.5 grams per day.

2. Assuming the egg loses 0.20 g per day, the age of the egg is:
$(68.8\text{g} - 62.42\text{g}) \times \frac{1 \text{ day}}{0.20\text{g}} = 32$ days old

3. Measure the volume by water displacement.

4. Larger eggs have smaller shape indexes.

5. Extra large eggs are usually more than 70 g, and medium eggs are less than 50 g.

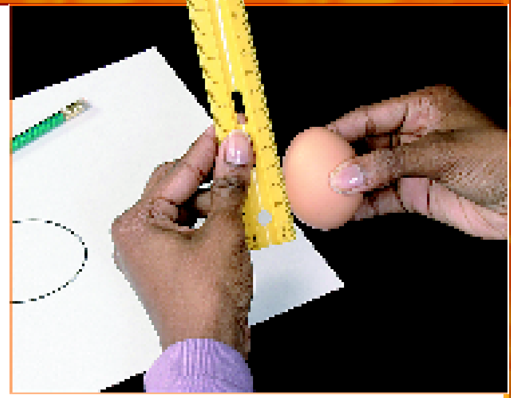
6. $2HCl + CaCO_3 \rightarrow CO_2\,(g) + H_2O + CaCl_2$

7. Both powdered milk and the eggshell produce a violet color.

8. Measure the mass of a refrigerated egg for three days. Measure its mass for three more days while storing it at room temperature. The warmer the temperature, the greater the mass loss.

Small-Scale LAB

The Egg: A Biochemical Storehouse



Purpose

To explore some physical and chemical properties of a chicken egg

Materials

- chicken egg
- ruler
- balance
- pencil
- paper

Procedure

Obtain a chicken egg. Examine the egg's shape and measure its length and width in centimeters. Measure the mass of the egg. Make an accurate, life-size sketch of your egg and record all your data on the sketch.

Analyze

Using your experimental data, record the answers to the following questions below your drawing.

1. A common way to compare the shapes of eggs is by using a shape index. The shape index is the width of an egg expressed as a percentage of its length.

$$\text{Shape index} = \frac{\text{width}}{\text{length}} \times 100\%$$

Calculate the shape index of your egg.

2. The volume, original mass (when freshly laid), and surface area of an egg can easily be estimated by using the following equations.

$V = (0.5236)(lw^2)$ $m = (0.5632)(lw^2)$
$A = (3.138)(lw^2)^{2/3}$

V = volume m = original mass
A = surface area l = length w = width

Use your data to calculate the volume, original mass, and surface area of your egg. Show your work, and record your results.

3. Compare your measured mass of the egg with your calculated mass. Which is greater? Suggest why the mass of an egg might change over time.

4. Using your measured mass and your calculated volume, calculate the density of your egg. Compare this value with the density of a freshly laid egg ($d = 1.075 \text{ g/cm}^3$).

You're the Chemist

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. **Design It!** Design an experiment to answer the following question: Does the mass of an egg change over time?
2. **Analyze It!** Using your measured mass, your calculated original mass, and your experiments on the mass loss of an egg over time, estimate the age of your egg. What assumptions must you make?
3. **Design It!** Design and carry out an experiment to measure the volume of your egg. Write down what you did and what you found.
4. **Design It!** Carry out a series of experiments, or consult with your classmates and use their data, to determine if and how the shape index varies with the size of the egg (small, medium, large, extra large, jumbo).
5. **Analyze It!** Determine how the mass of an egg varies with its size (small, medium, large, extra large, jumbo).
6. **Analyze It!** An eggshell contains a calcium carbonate matrix with a protein cuticle. Place one drop of HCl on an eggshell and observe what happens. Write a chemical equation for this reaction. **CAUTION** *HCl is caustic and can burn skin.*
7. **Analyze It!** Proteins can be detected by adding aqueous solutions of copper(II) sulfate and sodium hydroxide to a sample. A violet color indicates the presence of protein. Test powdered milk and an eggshell for protein. What are your results?
8. **Design It!** Design and carry out an experiment to answer the following question. Does temperature affect the mass of an egg over time?