Proteins are complex molecules that make up as much as 50% of the dry weight of living cells. Proteins have a diverse nature. This makes it possible for them to play many roles in living organisms as well as in food products.

The primary sources of dietary protein are eggs, dairy products, meat, poultry, and fish. Specific cooking principles must be followed when preparing these foods due to their high

Objectives

After studying this chapter, you will be able to

- identify amino acid classifications based on nutritional use and chemical properties of the side chains.
- describe the primary, secondary, and tertiary structures of proteins.
- list at least six factors that denature proteins.
- state the functions of protein in food production.
- apply basic principles of the chemistry of protein to cooking eggs, milk, and meat products.
- compare the nutritional functions of proteins with the functions of carbohydrates and fats.

Key Terms

- amino acid
- amine group
- peptide bond
- polypeptide
- essential amino acid
- complete protein
- incomplete protein
- disulfide cross-link
- hydrophobic
- casein
- whey
- myoglobin
- oxidation
- reduction
- denaturation
- coagulation
- gluten
- protein gel
- albumin
- collagen
- aldehydes
- Maillard reaction

Proteins are complex molecules that make up as much as 50% of the dry weight of living cells. Proteins have a diverse nature. This makes it possible for them to play many roles in living organisms as well as in food products.

The primary sources of dietary protein are eggs, dairy products, meat, poultry, and fish. Specific cooking principles must be followed when preparing these foods due to their high
protein content. These foods provide the body with an important nutrient that serves many functions.

**The Structure of Protein**

Proteins are largely composed of the same elements as carbohydrates and fats—carbon, hydrogen, and oxygen. In addition, proteins contain nitrogen and usually sulfur. Some proteins also contain iron, copper, phosphorus, or zinc. Like carbohydrates, protein molecules are made up of subunits. These subunits are organic acids—acids that contain carbon atoms. All organic acids, like fatty acids, contain carboxyl groups (–COOH).

**Amino Acids**

The organic acids in proteins are called amino acids. Amino acids have three basic parts to their structure. They have a side chain of carbon and hydrogen atoms, a carboxyl group, and an amine group. The amine group is one nitrogen and two hydrogen atoms bonded to a carbon atom. It can be represented by –NH₂ or as the following chemical formula:

\[
-N-\ H
\]

There are 20 amino acids in the human body. As many as 150 more amino acids have been isolated in animals, plants, and single-celled organisms. Generally, the amine and carboxyl groups in an amino acid are bonded to the same carbon atom. Chemists use the letter R to represent the various carbon side chains. Therefore, most amino acids can be represented by the following formula:

\[
\text{carbon side chain } \rightarrow \text{R} \quad \text{O}
\]

\[
\begin{align*}
N & \quad \text{C} \quad \text{C} \quad \text{O} \quad \text{H} \\
H & \quad \text{H} \quad \text{H} \quad \text{R} \quad \text{O}
\end{align*}
\]

Because of its polar nature, the carboxyl group acts as an acid and the amine group as a base. The amine group from one amino acid will readily combine with the carboxyl group of another. When two amino acids combine, a water molecule is released. The bond formed between the two amino acids is called a peptide bond.

The new dipeptide is a protein molecule made from two amino acids. It also has an amine group on one end and a carboxyl group on the other.

Proteins are chains of many amino acids bonded together. The shortest known protein is a chain of 20 amino acids. Most proteins have from 100 to 500 amino acids. Because of the many peptide bonds, proteins are also called polypeptides. Polypeptides are molecules with many peptide bonds.

**Amino Acids Essential for Good Nutrition**

There are two ways to classify amino acids. Amino acids can be classified based on nutritional use. They can also be classified as to the chemical nature of their side chains.

The 20 amino acids used in the human body are necessary for growth and body functions. The body can make many of these amino acids as they are needed. It is not essential for them to be provided by the diet. However, 8 of the amino acids cannot be produced by the body. They are leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. These amino acids are classified as essential amino acids. Essential amino acids are amino acids that must be supplied by foods in the diet. The body cannot grow new tissue or maintain health without these 8 amino acids. See 11-1.

A ninth amino acid, histidine, is also essential for infants and toddlers. The body cannot make enough histidine to meet the demands of the rapid growth that occurs in early childhood. Extra histidine from complete proteins is needed daily.

Foods that contain all 8 essential amino acids are called complete proteins. Most complete
proteins come from animal sources and include eggs, milk, fish, poultry, and meats. One plant source of protein—soybeans—is also known for being quite high in quality. Before soybeans can support growth, they must be heat processed for several hours. This destroys toxic compounds that prevent use of the essential amino acid trypsin. Soybeans are low in methionine, and most soy products have methionine added to improve the quality of the amino acids.

Other plant sources of protein come from grains and vegetables. These proteins tend to be lower in quality and are called incomplete proteins. Incomplete proteins are short of one or more of the essential amino acids needed for human growth. The amino acids that are short are called limiting amino acids. For instance, lysine is often the limiting amino acid in cereal grains. Tryptophan and threonine are also limiting amino acids in some cases.

Vegetarians must choose plant foods carefully to receive all 8 essential amino acids necessary for good health. Vegetarians can combine some sources of incomplete protein to form a complete source. Combining legumes with grains, nuts, or seeds will generally create a complete source of protein. See 11-2. Some combinations that contain adequate amounts of all 8 essential amino acids are:
- whole wheat bread and peanut butter
- rice and red beans
- refried beans and corn tortillas
- hummus—a dip made with chickpeas and sesame seeds

Classification of Amino Acids by Side Chains

The second method for classifying amino acids is based on the chemical properties of the side chains. The way the protein molecule

### Essential Amino Acids

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Symbol</th>
<th>Structure of Side Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoleucine</td>
<td>I</td>
<td>(-\text{CH} - \text{CH}_2 - \text{CH}_3)</td>
</tr>
<tr>
<td>Leucine</td>
<td>L</td>
<td>(-\text{CH}_2 - \text{CH} - \text{CH}_3)</td>
</tr>
<tr>
<td>Lysine</td>
<td>K</td>
<td>(-\text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{NH}_2)</td>
</tr>
<tr>
<td>Methionine</td>
<td>M</td>
<td>(-\text{CH}_2 - \text{CH}_2 - \text{S} - \text{CH}_3)</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>F</td>
<td>(-\text{CH}_3 - \text{CH}=\text{CH})</td>
</tr>
<tr>
<td>Threonine</td>
<td>T</td>
<td>(-\text{CH} - \text{OH})</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>W</td>
<td>(-\text{CH} - \text{N} - \text{H})</td>
</tr>
<tr>
<td>Valine</td>
<td>V</td>
<td>(-\text{CH} - \text{CH}_3)</td>
</tr>
</tbody>
</table>
Although this meal does not include meat, the combination of red beans and rice provides all the essential amino acids.

is shaped and how it functions depend on the polarity of the side chains. Side chains can be nonpolar, uncharged polar, positively charged, or negatively charged.

Alanine, tryptophan, and leucine are examples of amino acids with nonpolar side chains. Nonpolar side chains are less soluble in water. However, because they are nonpolar, they are attracted to other nonpolar compounds, such as lipids and cholesterol. For instance, you read in Chapter 10 about lipoproteins, which are clusters of lipid and protein molecules. Some lipoproteins transport cholesterol in the blood. They are able to do this because the protein molecules in the lipoprotein clusters have nonpolar side chains. These side chains are positioned toward the outsides of the molecules, allowing them to attract cholesterol molecules.

A second group of amino acids has neutral polar side chains that will form hydrogen bonds. These side chains are attracted to other polar molecules, such as water. The hydroxyl group causes such a polar nature on serine, threonine, and tyrosine. The hydrogen bonding can also form between sections of the protein molecule. These hydrogen bonds are partially responsible for the shape a molecule will take. They are also partially responsible for some of the protein's physical properties and how proteins function in food preparation.

A third group of amino acids has side chains that have a positive or negative charge.

Positively charged amino acids, such as lysine and arginine, have a second amine group on the molecule. Negatively charged amino acids are aspartic and glutamic acid. The presence of positively and negatively charged side chains enables some proteins to act as buffers.

Protein Structures

The number of possible protein structures is endless. However, all protein molecules are complex. This is due to the number of amino acids and the order in which they combine. It is also due to the interaction between the side chains.

Primary Structure

The primary structure of a protein molecule is the order the amino acids occur in the chain. Food scientists have "maps" of food proteins, such as casein from milk. These maps identify the order of the amino acids. The primary structure is a result of the chain of peptide bonds formed in making the protein molecule.

Secondary Structure

The secondary structure of a protein molecule refers to the shape of sections of the amino acid chain. The secondary structure is due to hydrogen bonding between amino acids. These bonds cause bending of the molecule. The peptide bonds change direction based on the types of amino acids that are joined. Secondary structures of protein occur in three patterns: helix, random coil, and pleated sheet.

A helix structure is a repeating coil. Think of the shape of a Slinky or a telephone cord. That is a helix shape. The amino acid side chains are on the outside of the helix. As the amino acids twist around a central axis, hydrogen bonds form between amino acids on the chain. These hydrogen bonds increase the stability of the molecule.

A random coil shape forms when some of the side chains prevent the setting up of a helix. If you have ever played with a Slinky, you have probably had it eventually tangle. One of the sections would become twisted backwards. This is similar to what happens with random coils. It is like grasping and balling up a string. The string becomes twisted
and turned and folded in on itself with no set pattern.

The third shape common in protein molecules is the pleated sheet. This shape is much like the paper fans you may have made as a child. Side chains can be located both above and below the pleated sheet. This enables side chains of one molecule to bond to side chains in protein molecules above and below.

**Tertiary Structure**

The tertiary structure of a protein molecule refers to the three-dimensional structure of an entire amino acid chain. Think of the primary structure as the individual fibers in a piece of yarn. The secondary structure would be like the fibers twisted together into a ply of yarn. The tertiary structure is like a balled up strand of yarn. The main tertiary structures are globular (balled up) and fibrous (strands). See 11-3.

**Globular proteins** do not tend to form links that will create a protein network. Hemoglobin, which carries oxygen in the blood, and lipoproteins, which carry cholesterol in the bloodstream, are globular proteins. Casein in milk and albumin in egg white are other examples of globular proteins.

**Fibrous proteins** are usually made from helix-shaped strands. They are strong and are part of connective tissues. Collagen, elastin, keratin, and myosin are examples of fibrous protein. These proteins are found in muscle fibers, ligaments, tendons, fingernails, and hair. Fibrous proteins tend to link to form a network of tissue.

**Molecular Interactions of Proteins**

As you have read, proteins have a complex nature, large size, and various side chains. These factors allow many interactions within protein molecules and with other compounds. Understanding these interactions will help you understand the many ways proteins can function in food preparation.

A hydrogen bond can occur between the hydrogen atom of one side chain and the hydroxyl group of another. A hydrogen bond can also occur between the oxygen atom in one peptide bond and the hydrogen atom of another peptide bond. The formation of hydrogen bonds is basic to the stability of the secondary and tertiary structures of protein molecules. Polar groups on the outside of protein molecules also allow protein molecules to hydrogen bond with water. This is why some proteins are water soluble. Albumin, the protein found in egg white, readily dissolves in water. Water that is hydrogen bonded to protein is an example of bound water.

![Diagram of Protein Structures](image-url)

11-3 Peptide bonds link amino acids into a chain, forming the primary structure of a protein molecule. Hydrogen bonds between the C=O and N–H groups of a peptide chain cause the chain to fold into a secondary structure. Hydrogen bonding among sections of the side chains result in the formation of the tertiary structure.
A second interaction that occurs between protein molecules is disulfide cross-links. Disulfide cross-links are covalent bonds that form between two protein molecules at side chains that contain sulfur. The more disulfide cross-links that are formed, the more stable the protein will become.

A third molecular interaction of proteins is between nonpolar side chains. These interactions are called hydrophobic, or water repelling. These interactions occur between side chains with carbon rings.

Remember, nonpolar side chains are not water soluble. They do not form covalent bonds. However, nonpolar side chains can react with lipids. Hydrophobic side chains enable proteins to form lipoproteins, which are an important part of cell walls. Proteins that are water soluble tend to have the hydrophobic side chains facing into the center of the protein molecule.

An example of a hydrophobic protein is casein found in milk. This protein is vital to the forming of curds in cheese making. When a mixture of rennin, salts, and acids are added to milk, the globular casein untangles. The nonpolar side chains of the casein bind with milkfat, calcium, and one another to form curds. See 11-4.

A by-product of cheese production is whey. Whey looks like a watery milk and is mainly composed of a group of water-soluble proteins, lactose, and minerals. It is used as an additive in many commercially processed foods. The water-soluble proteins in milk are called whey proteins. They form hydrogen bonds with water. Whey protein molecules do not change their shape in reaction to rennin, salts, and acids the way casein molecules do.

Color Changes of Protein Pigments

Understanding color changes in protein pigments helps food scientists control color changes in meat during storage and processing. This is important because consumers believe that bright red color means meat is fresh. Myoglobin is the iron-containing protein pigment in muscle tissue that provides the color. Myoglobin stores or holds onto oxygen in live animal tissue. When an oxygen molecule is attached, myoglobin is a bright cherry-red color. When oxygen is not present, the tissue becomes purplish in color. After prolonged exposure to oxygen, the myoglobin changes to metmyoglobin which has a brown color. The process of adding oxygen is a reversible chemical reaction. This reversible process of adding and removing oxygen to a compound is called oxidation and reduction. Oxidation adds oxygen and reduction removes it. Hemoglobin is the other protein that uses the oxidation/reduction process to distribute oxygen in the body. Hemoglobin is found in the blood and myoglobin is found in muscle tissue.

Once meat is bright red, it can be quickly wrapped in packaging that limits exposure to more oxygen. Although the bright red color does not guarantee freshness as compared to a purplish or brown color, consumers will choose the bright red meat over other colors. Consumers commonly mistake red juice from meat as blood. Red juice that pools around meat cuts is water with dissolved myoglobin, not blood that contains hemoglobin.

Nitrites are added during curing processes to preserve meats. They also maintain a pink or red color and are very stable. Nitrite combines with myoglobin to form nitric oxide myoglobin. When cooked, this is converted to

11-4 These cheese curds were formed when globular casein molecules untangled, allowing nonpolar side chains to bind with milkfat and one another.
nitrosohemochrome causing the pink or red of cooked ham and bacon. When fresh or cured meats develop green or yellow discolorations, it is a sign of bacterial growth.

**Denaturation of Proteins**

Protein is unique in that its shape can be changed without changing the primary structure of the molecule. The secondary and tertiary structures of protein are fragile. They can be changed by physical or chemical means. Any change of the shape of a protein molecule without breaking peptide bonds is called **denaturation**. Denaturation usually results in a loosening or unfolding of the protein molecule.

Denaturation is sometimes reversible. If the denaturation is slight, the protein will tend to return to its original shape. Protein will also tend to return to its original shape if the denaturation involves only hydrogen bond interactions. You can see an example of this by beating egg whites until frothy or foamy. If you allow the egg whites to sit, they will return to their liquid state.

Denaturation of proteins is usually not reversible. This is the case when denatured proteins interact with other proteins while unfolded. Breaking disulfide cross-links is also irreversible denaturation.

Another type of permanent denaturation is coagulation. **Coagulation** results when a liquid or semiliquid protein forms solid or semisoft clots. One example of coagulation is milk curdling to form cheese. Cooked eggs are another example of coagulation due to permanent changes in disulfide links. Eggs are liquid before they are heated. After heating causes eggs to begin coagulating, they will not return to their liquid state. See 11-5. Gelatin, on the other hand, solidifies as it chills due to the formation of hydrogen bonds. When the gelatin is heated, the proteins return to a liquid state.

Denaturation will change many of the physical characteristics of a protein. If hydrophobic side chains are exposed through denaturation, a protein’s water solubility can be reduced. This can lead to proteins forming precipitates (solids) that can be separated from a mixture.

Denaturation can alter the ability of a protein to bind water. Cooking meat causes the proteins to shrink, releasing water-based fluids and reducing the ability to hold water. Some cooking is needed to kill bacteria and develop flavors. However, too much cooking causes too much coagulation. This results in protein foods that are dry, tough, and rubbery.

Denaturing protein can also interfere with the biological reactions of enzymes. You will read more about this in Chapter 12.

**Methods of Denaturing Protein**

Proteins can be denatured by a number of physical and chemical methods. Physical factors that denature proteins are hot and cold temperatures, mechanical actions, sound waves (including ultrasound), pressure, and irradiation. Chemical factors that denature proteins are pH changes (acid or alkali) and mineral salts. Because each protein is unique, the rate of the denaturing will vary greatly. The amount of denaturing that occurs also varies.

**Temperature Changes**

Heat is the most common method of denaturing proteins in food production. The amount of denaturation will depend on the temperature. Most chemical reactions double their rate with every 10°C increase in temperature. The rate of increase for protein denaturation is 600
times for every 10°C increase in temperature. This is because it does not take very much energy to break the hydrogen bonds.

Denaturation will occur at a faster rate when the protein is wet, as in food mixtures. This is because of interactions between the water molecules and the broken hydrogen bond sites.

Cold temperatures can also alter protein structures. This most often happens when foods are frozen. Milk that is frozen and then thawed will have a curdled look due to the denaturation of the milk proteins. Soy proteins and eggs are also likely to denature in freezing temperatures.

Mechanical Actions

Mechanical actions such as beating, rolling, and kneading can disrupt protein structures. Vigorous or prolonged actions will cause proteins to lock into new positions with other molecules. When bread dough is kneaded, proteins react with water and each other. They realign to form a viscoelastic (thick and stretchy) structure.

The network of elastic protein strands that give bread dough its structure is called gluten. The protein in wheat flour is responsible for this elasticity. Gluten changes its shape and strengthens during the kneading process. Gluten enables yeast breads to rise without tearing the dough. Gluten also enables breads to solidify during baking to form the main structure of the bread. This is why bread flours need a higher protein content than all-purpose or cake flour. See 11-6.

In some food products, care must be taken to avoid denaturing the protein too much. When beaten, egg whites will trap air and become light and fluffy. If overbeaten, overcoagulation occurs and unattractive clumps form.

Other Physical Methods of Denaturation

Several other physical methods can be used to denature protein. One of these methods involves the use of sound waves. It takes prolonged exposure to sound waves at high volumes to cause permanent denaturation. Another physical means of denaturation is irradiation. This will be discussed in detail in Chapter 21.

Chemical Methods of Denaturation

Some of the methods used to denature proteins involve chemical factors. One such method is a change in pH. Exposure to acids or alkalis can cause proteins to unfold. The pH needed to denature proteins will vary. Each type of protein has a pH range in which it is stable.

It is important for food scientists to know what pH range results in denaturation for each protein. The scientists can then put this information to use in developing food products. For example, soy proteins will dissolve into a sticky liquid in alkali. By forcing this liquid through tiny holes into an acid bath, the protein will coagulate into stringy fibers. These fibers resemble the texture of meat. The denatured soy protein is then used to make simulated meat products.
Add vinegar or lemon juice to milk and note the coagulation and curdling caused by the low pH. Many dairy products, such as sour cream, buttermilk, and yogurt, are the result of acids denaturing the milk proteins.

Poached eggs are best when cooked in water with a little vinegar added. The vinegar (acetic acid) coagulates the egg protein, which helps keep the egg compact. Try poaching eggs with and without vinegar and note the shape of the cooked eggs.

Another chemical method of denaturing proteins is exposing proteins to mineral salts or metals. Sodium and potassium salts will react to some extent with proteins, causing denaturation to occur. This is why adding salt early in the cooking process of high-protein legumes can cause some toughening of the product. Metals such as copper, iron, magnesium, and calcium will readily react with proteins. The presence of calcium is important in the curdling process in cheese production.

Functions of Protein in Food

A full understanding of all the interactions of protein in food production is not possible. The combination of so many complex proteins in equally complex food mixtures makes identifying all the interactions and reactions difficult. However, it is possible to study the proteins involved in some simpler food mixtures. It is also possible to examine types of functions proteins perform in foods. Some of these involve proteins being used as gelling agents, texturizers, emulsifiers, and foaming agents. Protein is also important in dough formation in baked products.

To determine how effectively proteins will work in a given food product, food scientists analyze some important physical characteristics. Proteins have varying degrees of water absorption, solubility, and viscosity (ability to flow when poured). Each protein’s viscosity and reaction to water can be altered through denaturation.

Form Gels

In Chapter 9, you studied the ability of starches to form gels. You learned that gels can be produced by cooking amylose in liquid to the gelatinization point to make sauces. Gels can also be made by combining pectin, sugar, and acid as in jellies. Proteins have the ability to form gels, too. This is what happens when the protein gelatin is heated in water and then cooled. It is also what happens when a mixture of eggs, milk, and sugar is heated to make custard.

A protein gel is a mixture of mostly fluids locked in a tangled three-dimensional mesh. This mesh is made of denatured and coagulated proteins. Protein gels contain long, thin, chain-like polymers of amino acids. The molecules are cross-linked randomly to produce gels that behave like a rigid solid. Protein gels have two parts: the three dimensional molecular structure and the liquid that is attracted to the proteins. The liquid keeps the proteins from collapsing, and the proteins keep the liquid from flowing away.

Unlike starch gels, gelatin has a narrow melting and solidifying temperature range. Starches begin to gelatinize as they are cooked and form gels as they cool. Some protein gels are very liquid when hot and thicken when they cool. The coagulation process is gradual and requires lower temperatures than starch gels. Like most starch gels, gelatin is softened by acids and may develop syneresis (leakage) if cooked or stored too long.

To make a protein gel, plain gelatin is first dissolved in cold water. If hot water is added first, it will cause the gelatin to clump, making it difficult to dissolve. The cold water causes the gelatin molecules to swell. Boiling water is then added to disperse the gelatin. Dispersion occurs at 35°C (95°F). The gel forms when the mixture is cooled to between 10°C (50°F) and 16°C (61°F). See 11-7.

Gelatin dessert mixes are prepared by first adding boiling water to dissolve the gelatin. Boiling water does not cause clumping because the gelatin particles in dessert mixes are separated by sugar and flavoring.
Stiffness of protein gels increases with standing at cool temperatures. Gelatin will set quickly when ice cubes are added to lower the temperature of the dispersed mixture. However, a gelatin that is set quickly will melt more quickly at room temperature than a gel that sets slowly.

Once gelatin is rehydrated, it must be kept refrigerated. Gelatin will lose its rigid structure and become runny at room temperature. It will also be susceptible to bacterial growth.

Protein gels are strengthened by several factors. The more gelatin a mixture contains, the firmer the gel will be. However, too much gelatin causes the product to become gummy. Mineral salts will add strength to the gel by helping to establish the cross-linkages in the structure. Because of this, hard water or milk will produce a firmer gel than distilled or softened water.

Gels are weakened by acid, sugar, and fruit or vegetable pieces in the mixture. Gelatin can have up to 30 mL (2 tablespoons) of lemon juice added per 250 mL (1 cup) of liquid. This amount of acid will not keep a gel from forming. Sugar slows the gelling process as well as preventing some cross-linkages from forming. This results in a weaker structure. Most gelatin mixes carefully balance the gelatin and sugar. Pieces of fruits or vegetables break the flow of the three-dimensional gel structure. This mechanically interferes with the gelling process. If too much fruit is added, then gelatin concentrations must be increased to compensate.

You probably are familiar with gelatin as a jiggly, cool, easy-to-prepare dessert or salad. However, gelatin is also used as an additive in food products for the following reasons:
- to provide structure and support
- to stabilize the foam in whipped products
- to thicken puddings and pies
- to control crystal growth in frozen foods

A protein gel can also be formed from muscle tissue. Salt is added to destabilize some of the proteins. The meat or meat pieces are then massaged or tumbled. The salt pulls some proteins into solution. The agitation ruptures some cells, increasing the protein available for gelatinization to occur. This process is used on some hams, chicken hot dogs, bologna-type sausages, and a Japanese fish sausage.

**Texturize**

The texture or feel of protein can be changed from globular to fibrous by denaturation. Most globular proteins can be spun into fibers if there are few nonprotein compounds present. You have briefly read about this with reference to soy proteins being texturized for use as simulated meat products.

Another method of texturizing soy protein for use as meat substitutes involves heat-coagulation under pressure. High-protein soy flours are mixed with water, heated under pressure, and then extruded. Extrusion involves pushing the mixture through openings that shape the product. Flavoring and coloring are added to make the product more closely resemble meat. These texturized proteins can be mixed with meat to extend or stretch its volume. Hamburgers made with these texturized-protein extenders are lower in cost and fat content.

Protein texturization is also used in developing process cheeses. Different natural cheeses are mixed and then melted together by heating to about 71°C (160°F). The mixing and heating denature the proteins in cheese.
The protein, gelatin, is made from collagen extracted from the bones and hides of animals. Collagen is a protein in connective tissue. It is extracted from the raw material, mixed with water, and processed to form gelatin. The gelatin is then purified, refined, and dried.

Pure gelatin is nearly flavorless and odorless. It may be packaged and sold as unflavored gelatin. It can also be combined with artificial flavors, colors, and sugar and sold as flavored gelatin.

Gelatin is used to thicken chilled pies, gelatin desserts, and ice cream. Only 15 mL (1 tablespoon) of gelatin is needed to thicken 250 mL (1 cup) of liquid.

Gelatin is a rather insignificant source of nutrients. It provides only low-quality protein because it lacks the essential amino acid tryptophan. Most of the nutritional value of gelatin salads and desserts comes from added ingredients, such as fruits and vegetables.

When cooled, the process cheese has a smoother texture than the natural cheeses used in its production.

Emulsify

An emulsion is a stable mixture of a fat and a water-based liquid. Most stable emulsions have three parts. One part is a nonpolar substance, like fat. A second part is a polar liquid, like water. The third part of an emulsion is an emulsifier, which can be a denatured protein. An emulsifier is a molecule that has a polar end and a nonpolar end, 11-8. Emulsions usually require heat or mechanical action, such as beating, to denature the protein and then form the emulsion. Temporary emulsions of a fat and polar liquid usually are created by beating or shaking without an emulsifier present.

Egg yolk is an excellent protein emulsifier. It is often used in home recipes for ice cream and mayonnaise to keep the mixtures stable.

Other food product emulsions in which proteins act to keep the fats and liquids dispersed include milk, cream, butter, and cheese. The casein in milk, with its loose random coil structure, serves as a protein emulsifier in these foods. Homogenized milk is a stable emulsion for two reasons. Homogenization forces milk through screens under high pressure. This ruptures the membranes around the fat globules, reducing the size of the globules in the milk. The pressure used in the homogenization process also changes the structure of the casein molecules. This structure change makes the casein better able to bond to the fat.

Protein's ability to form emulsions can sometimes be a problem. For instance, soy, sunflower, and canola oil production involve separating protein and oil emulsions with minimal damage to either by-product. However, grain proteins can make it difficult to fully extract the oils from the grain kernels.

Form Foams

In a foam, gas is suspended in a liquid or semisolid. The gas is usually air or carbon dioxide surrounded by a film or bubble containing protein. In food production, foams are made in three main ways: bubbling gas through a mixture, whipping or beating, and depressurization.
As a child, you probably practiced the first method of forming foams. You would have done this by inserting a straw into a glass of cold milk and blowing. The bubbles that resulted were a foam formed by bubbling gas through a mixture. The elasticity of the protein molecules in milk makes this foaming action possible. This method can create very large foam volumes.

The second and most common method of forming foams is whipping or beating the protein mixture. Whipping gives a more uniform dispersion of gas than blowing air through a mixture. Small uniform bubbles tend to be more stable. Stiffly beaten egg whites are an excellent example of this method of making a foam.

The third method of forming foams uses a sudden release in pressure, as in aerosol cans. The release in pressure causes air spaces to rapidly expand. Dissolved air and liquid are released as a foam. Whipped cream in cans is the main example of this method. Another example of this method can be seen by opening a warm 2-liter bottle of root beer.

Food foams include meringue, foam cakes, marshmallows, whipped cream, whipped toppings, ice cream, soufflés, and bread, 11-9. All these products have a light texture due to gas being trapped within their structures. One protein that is a good foaming agent is albumin, which is found in egg whites and milk. Some caseins, whey, gelatin, glutenin, and soy protein are also good foaming agents. You will read about factors that affect the stability of food foams in Chapter 22.

Develop Gluten

Another main function of protein in food products is the development of gluten in baked goods. Gluten is a strongly cohesive and elastic protein. It is formed when wheat flour is combined with moisture and stirred or kneaded. The strength of gluten is partially a result of disulfide cross-links that form during mixing. As carbon dioxide is released in the dough, it forms tiny air pockets or bubbles. This causes the gluten structure to stretch. When baked, the gluten coagulates, forming the light airy texture of bread and other baked products.

The ability to form cohesive and elastic gluten is not present in other grains, such as rye and corn. This is why breads made with rye flour or cornmeal have a denser, heavier texture. Recipes for such breads usually
require at least as much wheat flour as flour or meal from other grains.

The addition of other proteins to bread doughs can increase the nutritional value. However, other proteins can also interfere with the development of the gluten network. Cold milk contains globular proteins that will interfere with gluten formation. Scalded milk has been denatured and does not interfere with the gluten structure. This is why most yeast bread recipes call for scalded milk.

**Cooking High-Protein Foods**

High-protein foods include eggs, milk products, meat, poultry, and fish. All these foods are damaged by cooking temperatures that are too high or cooking periods that are too long. This is because of the rapid denaturation of protein when heated. The protein molecules tend to shrink and lose water. Too much heat will result in a dry, rubbery, tough product.

**Principles of Storing and Cooking Eggs**

Two factors cause the deterioration of eggs in storage. The first is the loss of carbon dioxide through the eggshell. As carbon dioxide moves through the shell, the pH of the egg changes from neutral to basic. This causes the proteins to break apart.

The second factor that causes the deterioration of eggs in storage is part of the water moving into the egg yolk. This stretches and weakens the membrane surrounding the yolk. This is why it is harder to separate older eggs. It is also harder to turn a fried egg without breaking the yolk if the egg is not fresh.

Many egg producers apply a special spray to eggs to reduce the loss of carbon dioxide and moisture through the shell. This spray helps eggs maintain quality for a prolonged shelf life. See 11-10.

Lengthy storage is not the only factor that will affect the outcome of cooked eggs. Egg whites are composed of protein, water, riboflavin, niacin, magnesium, and potassium. Albumin, the protein in egg white, is easily denatured by heat. If eggs are heated at high temperatures or for long periods, the coagulation will be more extensive. This will result in a firm to tough egg white. Low temperatures and short cooking times will allow the egg white to coagulate while remaining soft and tender.

**Principles of Cooking Milk**

Milk-based products include white sauces, cheese sauces, puddings, and cream soups. Two common problems can occur when preparing such products. The first problem is curdling. *Curdling* occurs when acid causes
the globular casein protein molecules in milk to unfold and stick together. Curdling can be avoided by combining the acid with starch before the milk is added. Cream of tomato soup is an example.

The second common problem that can occur when cooking with milk is scorching. Scorching occurs when the protein clumps formed by the heat sink and burn to the pan. Whey proteins will begin to coagulate at 66°C (150°F). Constant stirring helps prevent scorching by keeping the whey proteins from sinking. Scorching can also be prevented by cooking milk-based products in a double boiler. A double boiler suspends the product over boiling water and steam. This keeps the temperature of the product lower than if it were in a pan in direct contact with the heat source. The lower temperature will help prevent the milk proteins from sticking and burning to the pan.

Casein will not coagulate unless concentrations are high or certain salts or acids are present. Pretreatment is necessary to prevent coagulation of casein in evaporated milk. Preheating alters the calcium salts that trigger coagulation. Stabilizers are then added just before concentration.

Technology Tidbit

"Eggs" actly Stable

Hens lay fewer eggs during the winter months than they do during other times of the year. To help stabilize the egg supply throughout the year, the food industry uses cold storage technology to slow egg deterioration.

Before eggs are placed in cold storage, they are dipped in a thin coating of mineral oil. This is done within 12 hours of laying. The coating reduces the loss of moisture and carbon dioxide through the porous eggshell. This helps stabilize the pH of the egg and maintain freshness.

The coated eggs are placed in a controlled atmosphere of carbon dioxide or ozone. This atmosphere must have 85% to 90% humidity and be at -1.5°C to 0°C (29°F to 32°F). This atmosphere will maintain egg freshness for up to 6 months.

Commercial cold storage costs money. This accounts for the rise in egg prices seen in some areas each year between Christmas and Easter.
Food Feature

Is My Chicken Done?

When you see a dark reddish stain near a chicken bone, you may wonder if the chicken is thoroughly cooked. The only reliable way to test the doneness of cooked poultry is with a meat thermometer. Insert the probe of the thermometer into the thickest part of the thigh of a whole bird. Insert the probe into the thickest part of individual poultry pieces. Make sure the probe does not touch bone. Whole birds and thighs should reach an internal temperature of 80°C (180°F). Breast pieces should reach an internal temperature of 75°C (170°F).

When eating out, you are not likely to have the opportunity to check cooked poultry with a meat thermometer. If you are in doubt about the doneness of poultry in such a situation, check the color of the meat juices. Press the poultry gently. If the juices from the meat are clear, the poultry is done. A light pink color on the outside portions of poultry is usually from a chemical reaction caused by smoking the meat. However, if the inner meat and meat juices have a pink tinge, the poultry may be undercooked. You can request further cooking. Even poultry that is thoroughly cooked according to a meat thermometer may have a dark reddish stain near a bone. This is caused by hemoglobin (blood protein) seeping out of the bone marrow during cooking. A dark reddish stain is more likely to happen in poultry that has been frozen. Such stains may also occur in poultry from very young birds. However, the stain is not related to doneness.

Cooking Tip
Baked custard is a sweetened milk and egg mixture that will curdle if overheated. You can use a technique that applies a principle similar to a double boiler to keep baked custard smooth. In the oven, place the pan filled with custard into another pan, which is partially filled with water. Water maintains a temperature of 100°C during heating. Therefore, it will protect the custard from the hotter temperatures of the oven.

Principles of Cooking Meat
Most meats contain three categories of proteins: muscle fibers, connective tissue, and myoglobin (deep red pigment). One of the goals in cooking meat is to soften the connective tissue to make the meat more tender. Collagen is a protein in connective tissue. It begins to soften and break down into gelatin when cooked in moist heat. Collagen in connective tissue of young animals (veal, lamb, and pork) does not begin to soften until it reaches 50°C (122°F). Collagen of older animals (beef and mutton) does not begin to soften until it reaches 60°C (140°F). Unfortunately, as the internal temperature of meat reaches 50°C (122°F) during cooking, muscle fibers will start to toughen. This means the heat needed to soften connective tissue toughens muscle fibers.

Roasts with much connective tissue need to be well done to allow enough time to soften connective tissue. Cooking a roast in 60°C (140°F) liquid would require five to six hours of cooking to soften connective tissue. This time and temperature combination makes the meat vulnerable to bacterial contamination. Boiling the roast for one hour will soften connective tissue without risk of bacterial contamination. However, muscle fibers will toughen considerably. The best balance seems to be simmering the roast in 86°C to 93°C
(180°F to 200°F) liquid for at least two to three hours. This time and temperature combination provides enough heat to soften connective tissue without excessive toughening of the muscle fiber. (Cuts of meat larger than 3 to 4 kg [7 to 9 pounds] will take longer.) Foodborne illness is not a risk if the meat is kept hot (above 60°C [140°F]) until it is served.

Meat with little connective tissue can be prepared with dry heat and shorter cooking times. Cooking time with dry heat methods is determined by the internal temperature of the meat. See 11-11.

The Maillard Reaction

When amino acids in grains and meats are heated at high temperatures, a three-phase chemical reaction occurs that causes a change in color and flavor. One step in this process is the oxidation or dehydrogenation of alcohols to compounds known as aldehydes. An aldehyde is an alcohol that has been dehydrogenated.

\[
\text{CH}_3\text{CH}_2\text{OH} \xrightarrow{\text{[O]}} \text{CH}_3\text{CH} = \text{O}
\]

The reaction between proteins and carbohydrates that causes food to brown when cooked is called the *Maillard reaction*. The chemist Louis Maillard first identified this reaction.

The Nutritional Contributions of Proteins

Protein is one of the energy nutrients. However, this is not its most important function. Protein is needed for growth and repair of body tissue. Protein is also needed for fighting disease, fluid and electrolyte balance, pH balance, and regulating body functions. See 11-12.

Support Growth and Repair

The most important function of protein in the body is to provide nitrogen and amino acids for growth and repair. Every cell in the body contains protein. As many as 10,000 proteins have been identified in a single human

### Daily Protein Needs

<table>
<thead>
<tr>
<th>Age</th>
<th>mg/kg Body Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infants (0 to 6 months)</td>
<td>2,000</td>
</tr>
<tr>
<td>Infants (6 to 12 months)</td>
<td>1,500</td>
</tr>
<tr>
<td>Children (1 through 6 years)</td>
<td>1,200</td>
</tr>
<tr>
<td>Children (7 through 14 years)</td>
<td>1,000</td>
</tr>
<tr>
<td>Adolescents (15 through 18 years) males</td>
<td>900</td>
</tr>
<tr>
<td>females</td>
<td>800</td>
</tr>
<tr>
<td>Adults (19 years and over)</td>
<td>800</td>
</tr>
<tr>
<td>Pregnant women</td>
<td></td>
</tr>
<tr>
<td>need an extra 10 g of protein per day</td>
<td></td>
</tr>
<tr>
<td>and lactating women need an extra 15 g.</td>
<td></td>
</tr>
</tbody>
</table>

11-12 People in every age group need high-quality proteins from animal sources or complementary plant sources.

### Recommended Temperatures for Cooking Meat and Poultry

<table>
<thead>
<tr>
<th>Product</th>
<th>Internal Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef and Lamb</td>
<td></td>
</tr>
<tr>
<td>Ground beef or lamb</td>
<td>71°C (160°F)</td>
</tr>
<tr>
<td>Medium rare</td>
<td>63°C (145°F)</td>
</tr>
<tr>
<td>Medium</td>
<td>71°C (160°F)</td>
</tr>
<tr>
<td>Well done</td>
<td>77°C (170°F)</td>
</tr>
<tr>
<td>Pork</td>
<td></td>
</tr>
<tr>
<td>Fresh, medium</td>
<td>71°C (160°F)</td>
</tr>
<tr>
<td>Fresh, well done</td>
<td>77°C (170°F)</td>
</tr>
<tr>
<td>Ground pork</td>
<td>71°C (160°F)</td>
</tr>
<tr>
<td>Ham, fresh</td>
<td>71°C (160°F)</td>
</tr>
<tr>
<td>Ham, precooked</td>
<td>60°C (140°F)</td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
</tr>
<tr>
<td>Chicken</td>
<td>82°C (180°F)</td>
</tr>
<tr>
<td>Ground poultry</td>
<td>74°C (165°F)</td>
</tr>
<tr>
<td>Turkey</td>
<td>82°C (180°F)</td>
</tr>
</tbody>
</table>

11-11 Checking internal temperatures with a food thermometer will ensure that meat and poultry are cooked to the desired degree of doneness.
Myoglobin is a protein that holds oxygen in muscle tissue. Myoglobin gives meat its color. It is also responsible for the color changes that take place in meat during cooking. Fresh meat has a red color because myoglobin is red when exposed to oxygen. Pork is lighter than beef because it contains less myoglobin. When meat is cooked, the heat causes myoglobin molecules to lose an electron. The result is a color change to brown.

Have you ever wondered why some pieces of chicken are white meat and some are dark? The color of chicken and turkey meat is related to the type of muscle fibers in the meat. The type of muscle fiber is based on the energy source used most often by those muscles. Breast and wing muscle fibers are designed for rapid sudden use. They burn glycogen for energy, which does not require oxygen. Legs and thighs have muscles designed for duration, or slow steady use. These muscles burn fat as well as glycogen. Oxygen must be present for fat to be turned into energy.

Like beef and pork, chicken and turkey meat contain the protein myoglobin. Myoglobin holds oxygen and is brown to red in color, depending on the amount of oxygen present. Because breast and wing muscles do not require oxygen to produce energy, breast and wing meat are light in color. Because leg and thigh muscles need oxygen to turn fat into energy, leg and thigh meat have a darker color. Fat stored in these muscle tissues also gives dark meat a higher fat content than white meat.

Duck and goose meat is all dark because these birds fly for long distances at a time during migration. This requires the fat and oxygen stores of dark meat. This is why duck and goose are fatter than chicken and turkey.

cell. Protein is used to make muscle fibers, connective tissue, cell walls, and red and white blood cells. Hair cells and nails also contain large amounts of protein. Whenever the body is injured, under stress, or ill, the need for protein increases.

Most body cells are replaced within a seven-year period. Cells lining the intestinal tract must be replaced every three days. Blood cells must be replaced every three to four months. Therefore, even adults need a daily supply of protein to replace worn out cells.

**Fight Disease**

A second key function of protein in the body is to help fight disease. Antibodies are proteins designed to attack foreign substances that enter the body. Whenever the body is exposed to germs, it manufactures antibodies designed to destroy those specific germs. Amazingly, the body remembers and produces more of those antibodies the next time it is exposed to the same germs.

**Maintain Fluid and Mineral Balance**

Another function of proteins in the body is performed by proteins in cell walls. These proteins help control the movement of water and minerals in and out of the cells. Too much fluid in the cells will cause cells to rupture. If cells contain too little fluid, they will die. Maintaining the right mineral balance is important for the nerves, brain, and muscles to function properly.
Maintain pH Balance

Proteins in the blood perform another important function in the body. Normal body processes result in the production of acids and bases. The blood must carry these acids and bases to the liver and kidneys to be processed or excreted. The pH of the blood must be maintained between a pH of 7.4 and 7.6. If the blood pH changes too much, it can cause coma or death.

Proteins in the blood control this important pH balance. These proteins are buffers that pick up acids or bases when there are too many. These proteins can also release acids and bases when the blood level drops too low. The polar side chains of the amino acids make this possible. The carboxyl group on an amino acid acts as an acid and the amine group acts as a base.

Control Bodily Functions

Proteins play a role in controlling many bodily functions. They do this by being a part of hormones and enzymes. Hormones are an important part of many body processes. For instance, the hormone insulin is involved in regulating glucose levels in the blood. Hormones control growth, regulate the reproductive system, and maintain other critical body functions. Enzymes are a necessary part of the many chemical reactions that occur within the body. Chapter 12 discusses the importance of these proteins.

Provide Energy

The body does not store extra protein or turn it into muscle. (This is contrary to what you might read in some ads for body-building protein and amino acid supplements.) When you consume more protein than your body needs, your body can change the amino acids into an energy source. Your body does this by removing the NH₂ and C=O. The NH₂ is turned into ammonia. The C=O becomes part of a compound known as ketones.

Recent Research

Browned Foods and Carcinogens

A new health concern in the news is the formation of possible carcinogens in baked and grilled protein-based foods. One of the compounds is called acrylamide. Acrylamide is a compound formed from glucose, fructose, and the amino acid asparagines. It is formed from the Maillard browning reaction. It forms in foods that are cooked at high temperatures. For example, the browner the crust on toast or French fries, the greater the acrylamide content.

It was first identified in food in April 2002 by a group of Swedish scientists. So far scientists have learned that it is harmful to the reproductive and development processes of rats and mice. More research is needed to determine if the low levels in the food supply are harmful to humans.

Recommendations are to maintain a balanced diet and
- avoid overcooking or using extremely high temperatures in cooking,
- fry foods to a light rather than dark golden brown,
- scrape dark crumbs off toast and baked items,
- soak and rinse potatoes before making homemade French fries.

"Acrylamide: Putting the Current Findings into Perspective," Food Insight: Current Topics in Food Safety and Nutrition, IFIC Foundation, May/June 2004
Both ammonia and ketones put a strain on the kidneys. A person must consume large volumes of water to flush these substances from the body. This is why high-protein, low-carbohydrate diets can be dangerous.

**Future Protein Needs**

When researchers compare present food production to world population projections, they predict there will be food shortages in the future. New sources of protein must be found if there is to be enough for everyone. Food scientists worldwide are working on several solutions to meet future protein needs.

One area of research is developing grains that yield higher levels of protein. *Triticale* is a cross of wheat and rye that has more protein than any variety of wheat. Triticale has improved cereal production in many developing countries. *Amaranth* is a traditional Aztec grain with high-quality protein. It has been found to grow in areas with very low rainfall. See 11-13. More work is needed to find tasty, high-protein grains that will grow without irrigation or fertilization.

Another area of research that may increase high-protein grain sources is biotechnology. Researchers are working at altering the genetic structure of plants. They hope to change incomplete protein sources to complete proteins. Care must be taken and extensive testing done to ensure that unwanted changes do not occur as well.

**Health Concerns**

Food allergies are the immune system's reaction to a protein in food that is mistaken for a harmful substance. Allergies to nearly 175 different foods have been documented. Symptoms can occur within seconds or may take as much as 72 hours to occur. Symptoms can vary dramatically from one person to another and one food to the next. Symptoms include but are not limited to hives, itching, tingling, swelling, red and watery eyes, sinus drainage, edema, swollen joints, vomiting, diarrhea, coughing, wheezing, dizziness, and anaphylaxis. Anaphylaxis is a severe life-threatening allergic reaction where swelling closes air passages, suffocating the victim. As little as one-fifth teaspoon of an allergen can cause death. The most common food allergens are peanuts, tree nuts, dairy, soy, wheat, eggs, fish, and shellfish.

Food sensitivities are allergic-like responses to nonprotein substances in food. They can be just as dangerous to the person who is susceptible and can have the same symptoms as a true allergy. Reactions to the additives sodium nitrite and nitrate are a common example.

Concerns for the food industry include accurate ingredient labeling to alert consumers of allergens, sharing equipment in the manufacturing process that can result in undeclared residues of allergens, and the use of processed ingredients that come from common allergens. For example, hydrolyzed vegetable protein could come from soy or wheat that are common food allergens.