2·14–2·18 Proteins are versatile macromolecules that serve as building blocks.

Hair and feathers are built from proteins.

2·14 Proteins are bodybuilding macromolecules.

You can't look at a living organism and not see proteins (**FIGURE 2-36**). Inside and out, **proteins** are the chief building blocks of all life. They make up skin and feathers and horns. They make up bones and muscles. In your bloodstream, proteins fight invading microorganisms and stop you from bleeding to death from a shaving cut. Proteins control the levels of sugar and other chemicals in your bloodstream and carry oxygen from one place in your body to another. And in just about every cell in every living organism, proteins called **enzymes** initiate and assist every chemical reaction that occurs.

Although proteins perform several very different types of functions, all are built in the same way and from the same raw materials in all organisms. In the English language, every sentence is made up of words and every word is formed from one or more of the 26 letters of the alphabet. With 26 letters we can write anything, from sonnets to cookbooks to biology textbooks. Proteins, too, are constructed from a sort of alphabet. Instead of 26 letters there are 20 molecules, known as **amino acids.** Unique combinations of these 20 amino acids are strung together, like beads on a string, and the resulting protein has a unique structure and chemical behavior.

Let's look more closely at the structure of the amino acids in the protein alphabet. They all have the same basic two-part structure: one part is the same in all 20 amino acids, and the other part is unique, differing in each of the 20 amino acids.

Proteins contain the same familiar atoms as carbohydrates and lipids—carbon, hydrogen, and oxygen—but differ in an

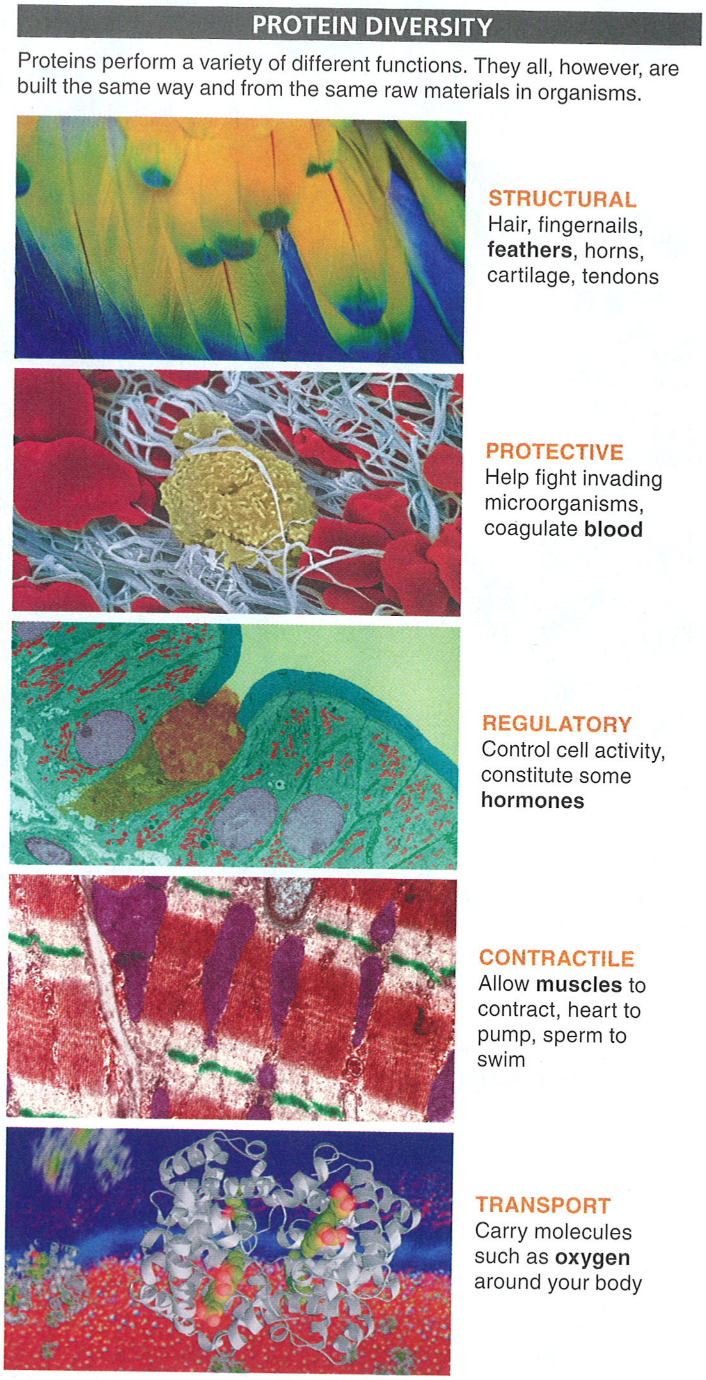


FIGURE 2-36 Proteins everywhere! Proteins are the chief building blocks of all organisms.

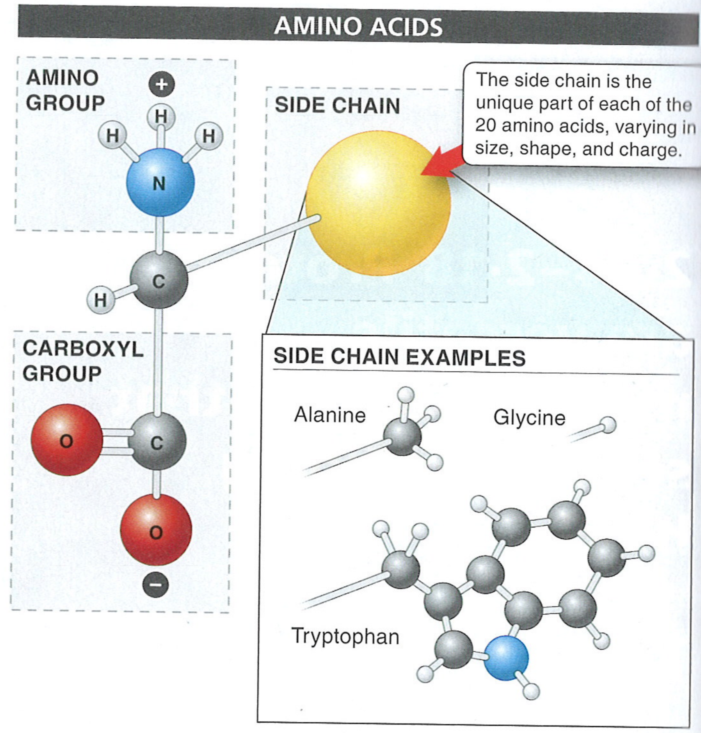


FIGURE 2-37 Amino acid structure. Amino acids are made up of an amino group, a carboxyl group, and a side chain.

important way: they also contain nitrogen. At the center of every amino acid is a carbon atom, with its four covalent bonds (**FIGURE 2-37**). One bond attaches the carbon to something called a **carboxyl group,** which is a carbon bonded to two oxygen atoms (one by a single bond and the other by a double bond). The second bond attaches the central carbon to a single hydrogen atom. The third bond attaches the central carbon to an **amino group,** which is a nitrogen atom bonded to hydrogen atoms (usually two or three). These components—the central carbon with its attached hydrogen atom, carboxyl group, and amino group—are the foundation that identifies a molecule as an amino acid and, as multiple amino acids are joined together, forms the "backbone" of the protein.

The fourth bond of the central carbon attaches to a functional group or side chain. This side chain is the unique part of each of the 20 amino acids. In the simplest amino acid, glycine, for example, the side chain is simply a hydrogen atom. In other amino acids, the side chain is a single CH_3 group or three or four such groups. Most of the side chains include both hydrogen and carbon, and a few include nitrogen or sulfur atoms. The side chain determines an amino acid's chemical properties, such as whether the amino acid molecule is polar or nonpolar.

TAKE-HOME MESSAGE 2·14

Unique combinations of 20 amino acids give rise to proteins, the chief building blocks of the physical structures that make up all organisms. Proteins perform myriad functions, from assisting chemical reactions to causing blood clotting to building bones to fighting microorganisms.

2·15 Proteins are an essential dietary component.

The atoms present in the proteins we eat—especially the nitrogen atoms—are essential to the growth, repair, and replacement that take place in our bodies. As we digest protein, breaking it down into its amino acids, our bodies use them for various building projects. Proteins also store energy in their bonds and, like carbohydrates and lipids, they can be used to fuel living processes.

The amount of protein we need depends on the extent of the building projects under way. Most individuals need 40–80 grams of protein per day. Bodybuilders, however, may need 150 grams or more a day to achieve the extensive muscle growth stimulated by their training; similarly, the protein needs of pregnant or nursing women are very high.

Q *Food labels indicate how many grams of protein are contained in a food item. Why is this information only partially helpful for effectively guiding your protein intake?*

Contrary to the impression you might get from food labels, all proteins are not created equal. Every different protein has a different composition of amino acids. And while our bodies can manufacture certain amino acids as they are needed, many other amino acids must come from our diet. Those that we must get from our diet—about half of the 20 amino acids—are called "essential amino acids." For this reason, we shouldn't just speak of needing "*x* grams of protein per day." We need to consume all of the essential amino acids every day.

Many foods, containing "complete proteins," have all of the essential amino acids. Animal products such as milk, eggs, fish, chicken, and beef tend to provide complete proteins. Vegetables, fruits, and grains often contain "incomplete proteins," which do not have all the essential amino acids. If you consume only one type of incomplete protein in your diet, you may be deficient in one or more of the essential amino acids. But two incomplete proteins that are "complementary proteins," when eaten together, can provide all the essential amino acids.

Traditional dishes in many cultures often include such pairings. Examples are corn and beans in Mexico and rice and lentils in India (**FIGURE 2-38**).

TAKE-HOME MESSAGE 2·15

Twenty amino acids make up all the proteins necessary for growth, repair, and replacement of tissue in living organisms. Of these amino acids, about half are essential for humans: they cannot be synthesized by the body so must be consumed in the diet. Complete proteins contain all essential amino acids, while incomplete proteins do not.

COMPLETE vs. INCOMPLETE PROTEINS

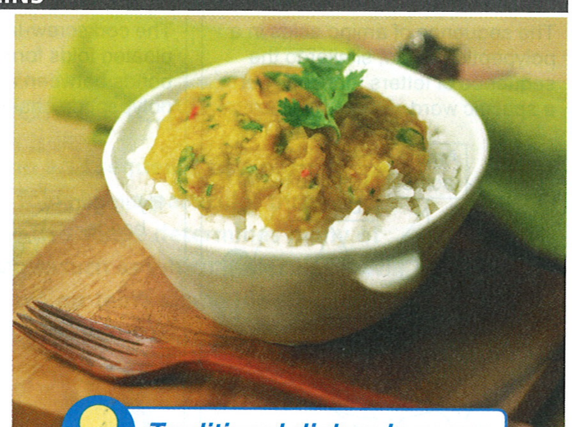
ESSENTIAL AMINO ACID CONTENT OF COMMON FOODS

	Apples	Almonds	White rice	Lentils	Milk - 2% fat	Tofu - firm (coagulated soy milk)	Chicken	Beef - T-bone steak
Histidine	●	●	●	●	●	●	●	●
Isoleucine	○	●	●	●	●	●	●	●
Leucine	●	●	●	●	●	●	●	●
Lysine	●	○	○	●	●	●	●	●
Methionine + Cysteine	○	○	●	○	●	●	●	●
Phenylalanine + Tyrosine	○	●	●	●	●	●	●	●
Threonine	○	●	●	●	●	●	●	●
Tryptophan	○	●	●	●	●	●	●	●
Valine	●	●	●	●	●	●	●	●

● Present at optimal levels
○ Not present at optimal levels

Optimal levels determined by the Institute of Medicine's Food and Nutrition Board

GRAPHIC CONTENT!
Thinking critically about visual displays of data.
Turn to p. 76 for a closer inspection of this figure.



Traditional dishes in many cultures combine proteins, bringing together all essential amino acids.

FIGURE 2-38 All proteins are not created equal. Some foods have "complete proteins" with all the essential amino acids. Other foods have "incomplete proteins," and we must consume proteins from multiple sources to get all the essential amino acids.

2·16 A protein's function is influenced by its three-dimensional shape.

Proteins are formed by linking individual amino acids together with a **peptide bond,** in which the amino group of one amino acid is bonded to the carboxyl group of another. Two amino acids joined together form a *dipeptide,* and several amino acids joined together form a *polypeptide.* The sequence of amino acids in the polypeptide chain is called the **primary structure** of the protein and can be compared to the sequence of letters that spells a specific word (**FIGURE 2-39**).

Amino acids in a polypeptide chain don't remain in a simple straight line like beads on a string. The chain begins to fold as side chains come together and hydrogen bonds form between various atoms in the chain. The two most common patterns of hydrogen bonding between amino acids cause the chain to either twist in a corkscrew-like shape or form a zigzag folding pattern. This hydrogen bonding between amino acids gives a protein its **secondary structure.**

The protein eventually folds and bends upon itself, and additional bonds continue to form between atoms in the side chains of amino acids that are near each other. Eventually, the protein folds into a unique and complex three-dimensional shape called its **tertiary structure.** The exact form comes about as the secondary structure folds and bends, bringing together amino acids that then form bonds such as hydrogen bonds or covalent sulfur-sulfur bonds (see Figure 2-37).

Some protein molecules have a **quaternary structure** in which two or more polypeptide chains are held together by bonds between amino acids in the different chains. Hemoglobin, the protein molecule that carries oxygen from the lungs to the cells where it is needed, is made from four polypeptide chains, two "alpha" chains and two "beta" chains.

Some proteins are attached to other types of macromolecules. *Lipoproteins,* for example, circulate in the bloodstream carrying fats. They are formed when cholesterol and a triglyceride (both lipids) combine with a protein. *Glycoproteins* are combinations of carbohydrates and proteins. These are found on the surfaces of nearly all animal cells and play a role in helping the immune system distinguish between your own cells and foreign cells. (We learn more about glycoproteins in the next chapter, which discusses cells.)

The overall shape of a protein molecule determines its function—how it behaves and the other molecules it interacts with. For proteins to function properly, they must retain their three-dimensional shape. When their shapes are deformed, they usually lose their ability to function. We can see

Q Egg whites contain a lot of protein. Why does beating them change their texture, making them stiff?

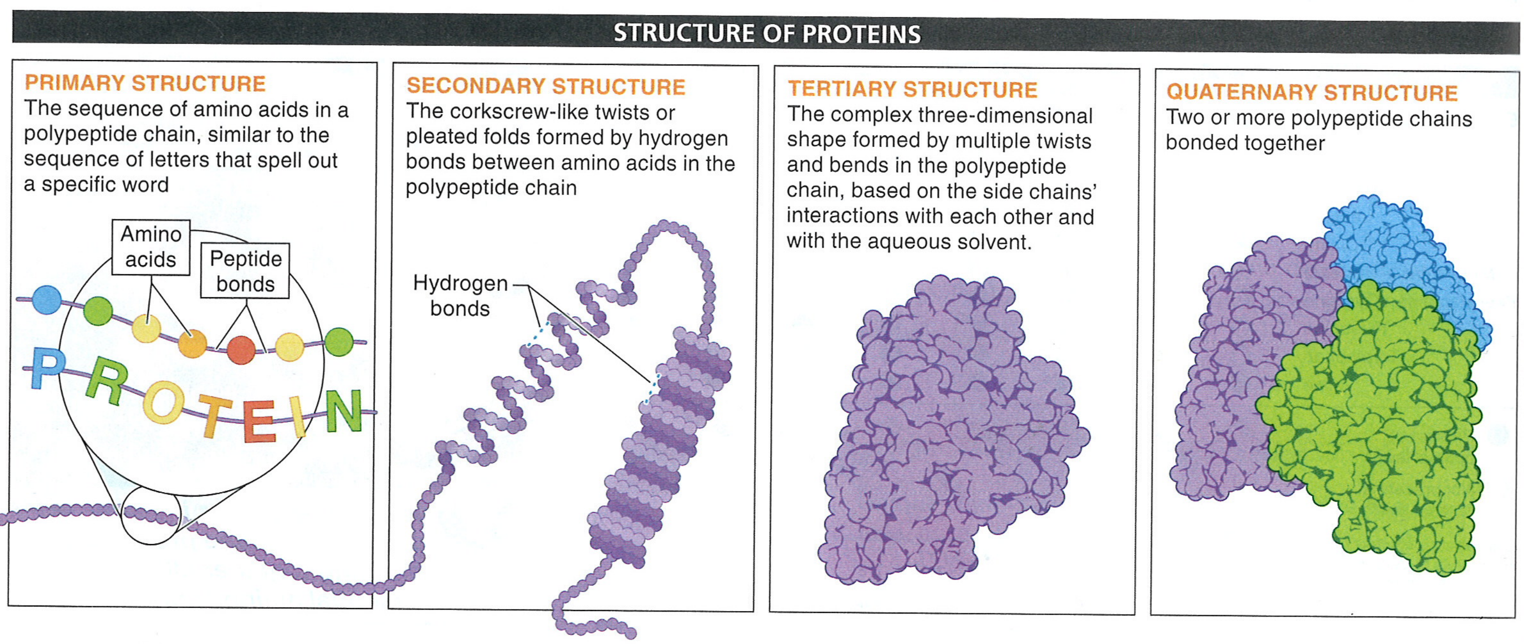


FIGURE 2-39 The several levels of protein structure. The functions of proteins are influenced by their three-dimensional shape.

proteins deforming when we fry an egg. The heat breaks the hydrogen bonds that give the proteins their shape. The proteins in the clear egg white unfold, losing their secondary and tertiary structure. This disruption of protein folding is called **denaturation** (**FIGURE 2-40**).

Almost any extreme environment will denature a protein. Take a raw egg, for instance, and crack it into a dish containing baking soda or rubbing alcohol. Both chemicals are sufficiently extreme to turn the clear protein opaque white, as in fried egg whites.

Hair is a protein whose shape most of us have modified at one time or another. Styling hair—whether curling or straightening it—involves altering some of the hydrogen bonds between the amino acids that make up the hair protein, changing its tertiary structure. When your hair gets wet, the water is able to disrupt some of the hydrogen bonds, causing some amino acids in the protein to form hydrogen bonds with the water molecules instead. This enables you to change your hair's shape—making it straighter or, if you manipulate it around curlers, making it curlier—if you style it while it's wet. The hair can then hold this shape when it dries, as the hydrogen bonds to water are replaced by other hydrogen bonds between amino acids of the hair protein as the water evaporates. Once your hair gets wet again, however, unless it is combed, brushed, or wrapped in a different style, it will return to its natural shape.

Whether your hair is straight or curly or somewhere in between depends on your hair protein's amino acid sequence and the three-dimensional shape it confers (**FIGURE 2-41**).

Q Why do some people have curly hair and others have straight hair?

FIGURE 2-41 **Curly or straight?** Proteins determine it!

This amino acid sequence is something you're born with (that is, it's genetically determined). The chains are more or less coiled, depending on the extent of covalent and hydrogen bonding between different parts of the coil. Many hair salons make use of the ability to alter covalent bonds to change hair texture semi-permanently. They are able to do this in three simple steps. First, the bonds are broken chemically. Second, the hair is wrapped around curlers to hold the polypeptide chains in a different position. And third, chemicals are put on the hair to create new covalent bonds between parts of the polypeptide chains. The hair thus becomes locked in a new position. (New hair will continue to grow with its genetically determined texture, of course, requiring the procedure to be repeated regularly.)

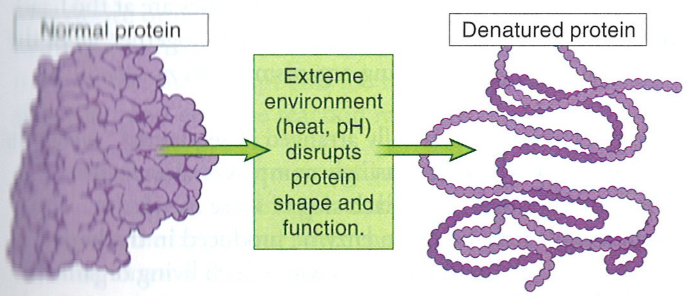


FIGURE 2-40 **Denaturation.** When proteins are unfolded, they lose their function.

TAKE-HOME MESSAGE 2·16

The particular amino acid sequence of a protein determines how it folds into a particular three-dimensional shape. This shape determines many of the protein's features, such as which molecules it will interact with. When a protein's shape is deformed, the protein usually loses its ability to function.