# CHAPTER 15

# THE STUFF OF INHERITANCE: DNA, RNA, AND MUTATIONS

## THE CHEMISTRY OF INHERITANCE

To understand what evolution is, what selection is, and how it works, we need to look at the physical mechanisms by which it occurs. This is basically the same style as distinguishing between the statement "the oven doesn't work" and addressing the problem. A stove—let's say, a gas oven—is a pretty simple device. Gas flows in through a pipe from a pipeline or tank; turning the regulator opens a valve that lets gas into the oven, and an ignition mechanism (heated electrical element, continuously burning flame—pilot light—from gas admitted through a small, continuously open valve) ignites the gas. The regulator valve also usually has a thermostat that will decrease or stop the gas flow when the desired temperature is reached. If the oven "doesn't work" we have to determine if the gas source is providing gas, if the ignition mechanism is working, and if the thermostat is functioning and allowing gas to enter. In a similar fashion, to understand what evolution is, in a sense somewhat more complete than "rabbits are brown to hide from their enemies," we need to have a sense of the components of evolution. In other words, we need to know what makes rabbits brown, and how evolution can create white and brown rabbits. Therefore this chapter addresses the following points:

- The pigment of a rabbit is made by enzymes.
- Enzymes are proteins
- Proteins are linear arrays of amino acids
- The body carries information on how to make these linear arrays of amino acids in genes, which are located on chromosomes.
- The genes are also linear arrays of molecules, but instead of being proteins, they are DNA.
- Enzymes, proteins, and DNA are macromolecules.

Most biological activity is carried out by the use of giant organic, carbon-based molecules. Because they are giant, they are called macromolecules. For instance, the blood pigment hemoglobin contains approximately 3,300 carbon atoms, over 6,000 nitrogen atoms, over 1,000 oxygen atoms, approximately 550 nitrogen atoms, and four iron atoms. Macromolecules are typically built by organisms by linking, usually end-to-end, a sequence of smaller molecules. The smaller molecules that are linked have many variations but some features in common.

## PROTEINS

Hemoglobin belongs to the class of macromolecules called proteins, which are defined as macromolecules consisting of chains of amino acids. An amino acid is a small carbon-based (organic) molecule that has both a group called an amine group and a group producing an acid. An amino acid might look a bit like this, with the amine and the acid both attached to the carbon:

Amine–Carbon–Acid

Carbon, however, can have up to four different atoms (things) attached to it, and in amino acids there is at least one major other component attached to the carbon. The other component is very variable. There are twenty of these other components. Some dissolve easily in water, while others do not. Thus each different amino acid has unique properties such as solubility. In spite of these unique properties, they all have the same basic structure:

Variable group<br>
↕<br>
Amine ↔ Carbon ↔ Acid

Proteins are long chains of these amino acids linked together through their amine and acid groups, with the variable groups sticking out of the chain. (In the diagram below, the carbon is symbolized simply by a "C" and the variable groups by V1, V2, etc.

$V_1$ ↕ $V_2$ ↕ $V_3$ ↕ $V_4$ ↕<br>
Amine↔ C↔ acid↔ amine↔ C↔ acid↔ amine↔ C↔ acid↔ amine↔ C↔ acid↔ amine

All the differences among proteins—between hemoglobin, steak, egg white, fingernails, hair, digestive juices, saliva, wool, and the gristle of meat—derive from the differences in the variable groups.

## CARBOHYDRATES AND FATS

Proteins are one major class of macromolecules. Other major classes include the **carbohydrates**, which are linkages of sometimes many thousands of sugars (small molecules consisting most commonly of six carbons, twelve hydrogens, and six oxygens). In carbohydrates, the manner in which the sugars are linked is important. Cellulose (wood, paper, or cotton) and starch have the same sugars, but they are linked differently. **Fats** have far fewer oxygens than other macromolecules and, by definition, dissolve in oils, gasoline, and similar substances. Finally, **nucleic acids** such as DNA are linear sequences of small but complex molecules called nucleotides. Thus, in general and in the simplest version, macromolecules can be symbolized as follows (M = Monomeric unit such as a sugar or amino acid):

$$M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M \leftrightarrow M$$

As you might guess, these chains do not simply lie there in straight rows. They can bend and wrap around each other. One of the most common structures of proteins that we know is a spiral; another is a pleated version (Fig. 15.1).

Straightening hair or curling it consists of using heat and water, or chemicals, to disrupt the natural spiral form of the hair protein, stretching the hair, and letting it settle into the pleated form, much as if you overstretched a spring. Eventually, if there is enough moisture around, as water or humidity, it will recurl into the alpha helix. This is why straightened hair becomes curly in humid weather, or curled hair restraightens. (Hair straighteners contain reducing agents that reduce (break) further links called disulfide bonds that strengthen the helices by binding amino acids across the loops. These bonds can then reform in other ways, maintaining a more permanent disruption of the helix.)

Some of these proteins have the ability to vastly speed up reactions. When they have this ability, they are called enzymes. For instance, even sterile beef, with no bacteria present, will eventually break down into amino acids, though this will take many, many years, even thousands of years. If a digestive enzyme such as pepsin or trypsin is present, the complete digestion of a mouthful of beef will take an hour or so. The enzymes can do this because they can fit very tightly against the protein molecules in the beef and bring the reacting parts together, much as when a key matches the tumblers in a lock, allowing the cylinder to rotate (Fig. 15.2).

Now we can deal with the question of the resources of evolution. An enzyme is needed to create the brown pigment. (Actually, many are needed, but for the

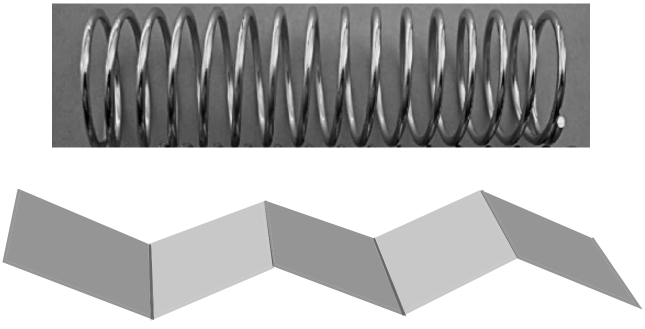

*Figure 15.1.* Many proteins can form a helix, as in the top figure (it is a particular type of helix, called alpha helix since Linus Pauling, who worked out which one it was, postulated several possible helices, which he described as alpha, beta, gamma, etc (A, B, and C in Greek). They also can form a pleated structure, called a beta pleated sheet, as shown in the lower figure. Hairs are long sequences of many of these proteins, aligned in the hair. Styling hair consists of stretching the normal form of the hair protein, the alpha helix, into the beta form. Heat and moisture can allow it to return to the alpha helix form, and so resume its original shape

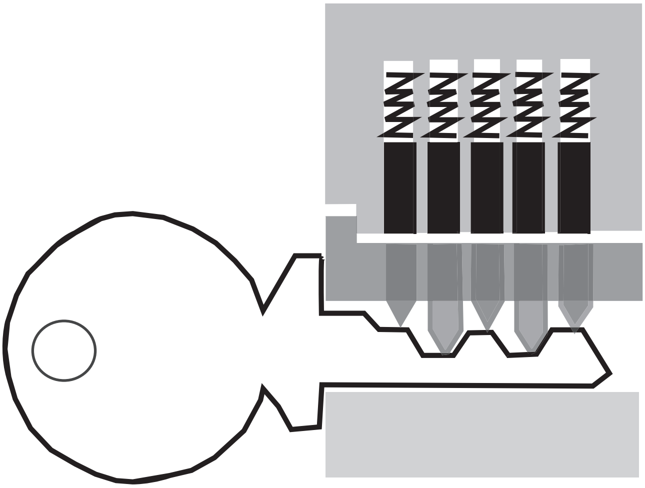

*Figure 15.2.* As a key must be specifically shaped to push the tumblers so that they are aligned (the cylinder turns at the junction between the gray pins and the spring-mounted black pins above them), a substrate must fit perfectly into an enzyme for the enzyme to be able to take it apart or be able to attach it to something else. If the enzyme is altered, which one could picture as having a big piece of dirt under one of the pins, the fit will not be perfect and the enzyme will not work

illustration one will suffice.) Because of the lock-and-key arrangement by which they work, a very small change will prevent an enzyme from working, as a newly-cut key will not work if there is a small burr or metal fragment left from the cutting. Such a very small change could be the substitution of one amino acid for another. Hemoglobin consists of four chains linked together, two pairs of identical chains. (Picture a four-stranded braid, with two brown strands and two blond strands.) Of the total of 584 amino acids in hemoglobin, changing two of them (one in each of the two identical strands) will create the disease called sickle-cell anemia. We know of several other instances in which the change of a single amino acid can change the character of the protein.

This, then, would be a mutation: a change in a specific protein that produces an identifiable difference between the individual carrying it and most other individuals. We would describe the difference as a mutant phenotype. We could even lose the protein altogether, for any of several reasons. In the simplest case, a visible change or mutation is caused by the switch of a single amino acid. How does this occur? The body builds, or synthesizes, these proteins from their building blocks or amino acids. Somewhere in the body an instruction manual must exist that tells the body in which order the amino acids must be added. This instruction manual is called the genome, the collection of genes that are instructions for the manufacture of individual proteins. As is described in more detail in Chapter 16, the genes, located on the chromosomes, are composed of DNA. DNA is a macromolecule consisting, like proteins, of a linear array of subunits. In this case the subunits are nucleotides.

A nucleotide is itself made of subunits, a base and a sugar called deoxyribose (the "D" in DNA"). The deoxyriboses are linked together by phosphates (combinations of phosphorus and oxygen) and form the backbone of the chain, with the bases sticking off the side like the variable "side chains" of the proteins.

| base | | base | | base | | base | | base | | base |
|---|---|---|---|---|---|---|---|---|---|---|
| ↕ | | ↕ | | ↕ | | ↕ | | ↕ | | ↕ |
| dRibose | ↔ P ↔ | dRibose | ↔ P ↔ | dRibose | ↔ P ↔ | dRibose | ↔ P ↔ | dRibose | ↔ P ↔ | dRibose |

The sequence of bases in the DNA is the information (code) for making the sequence of amino acids that will be the final protein. Suffice it to say that the change in a single base can result in a change in a single amino acid, and a change in a single amino acid can produce a noticeable difference in characteristics of an animal or plant. In fact, most mutations are alterations of a single protein, such as sickle-cell disease, or the ability to make brown pigment. So now we have an understanding of what will happen in evolution. If for any reason the DNA is altered so that the enzyme needed to make a brown pigment is abnormal, the rabbit will have a different color or perhaps no color at all. The alteration of the DNA can be as small as the change of a single base. In a very profound sense, evolution depends on the chemistry of DNA.

## REFERENCES
## STUDY QUESTIONS

1. If the question, "Why do monarch butterflies fly south in the fall?" is not a good scientific question, how would you rephrase the question to make it better? Explain.
2. How does an amino acid differ from a protein?
3. What is a macromolecule?
4. Proteins have the peculiar property that they are soluble only at certain levels of acidity, and precipitate in more acid conditions. What might you suspect that bacteria do to milk to make it curdle?
5. Because of the strength of the bonds that hold proteins and lipids together, biological lipids tend to melt at approximately 104° F (40° C), while protein structure falls apart at approximately 122° F (50° C). Do you think that this has anything to do with the fact that people tend to hallucinate when they have high fevers? How hot does water have to be for you to be burned by it?
6. If a protein can contain 1000 amino acids, why should the change of a single amino acid make a difference in how it functions? (Hint: wrap something like a flat electrical cord carefully around a suitably wide structure such as a broom-stick. Wrap the wire so that each loop lies side-by-side to the loops next to it. Now do the same thing but attach something the size of the plug to the middle of the wire. What happens?