Do you know that different cells have certain unique proteins that have unique jobs? Muscles have proteins that contract, enabling the muscle cell to contract. Pancreas cells make the protein insulin, which regulates blood sugar levels. Certain cells in the part of the brain called the hypothalamus make small unique proteins that trigger the release of pituitary hormones. There are proteins in nerve cells that work to create new contact points between nerve cells that store your memories? How many other examples can you think of cells with specific proteins?

Meet the Scientist
Linus Pauling (1901-1994)

A British journal included only Linus Pauling and Einstein from the 20th Century in their list of the greatest scientists in the history of the world. As you will see, Linus made major discoveries about chemical bonding and the structure of proteins—pretty heady stuff for a high-school dropout. He didn’t drop out because school was too hard. For him, school was too easy.

Figure 1. Linus as a young boy. From https://paulingblog.files.wordpress.co

Some scientists are born with a silver spoon in their mouth. But not Linus Pauling. From age 4 to 9, Linus lived in a small Oregon town, which was like an outpost in the Old West. The town had one street, lined by stores with false fronts on many of the buildings. The stores were like what you see on cowboy movie sets today. Real cowboys lounged in front of the general store. Real Indians camped on the edge of town. His father, Herman, was a self-taught pharmacist and "medicine man." He ran a drug store in town. Maybe that is why Linus developed a lifelong interest in chemistry. The family was very poor. In fact, they had to move to town in order to get help from his mother's family. But Linus was happy. For him, life was cowboys and Indians.

But Linus' happy childhood came to an end at age nine when his father died. His mother struggled alone to raise Linus and his two younger sisters. Linus found comfort in reading and collecting insects and minerals. By age nine, he had already read the entire Bible and Darwin's book, *Origin of the Species*. His father had made certain that Linus read important books. However, in those days good books were hard to find in a frontier town.

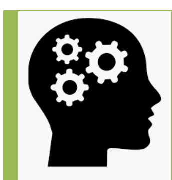
Linus's playmate had a chemistry set. The two of them spent many hours tinkering with it. They also spent many happy hours collecting rocks and minerals in a creek bed near town.

Linus wondered about the internal structure of rocks and minerals. Many years later, he answered some of those questions in his research lab.

By the time Linus was in high school, he was hooked on learning. But he dropped out of high school at age 16, because he had taken all the science that his school offered. His mother let him drop out, but insisted that he get a job and help support the family. He did such jobs as delivering milk, running film projectors, and working in a shipyard. He got a good job as an apprentice machinist, but he knew he had to go to college to fulfill the potential he knew he had. Linus commented in later years that his mother did not seem to understand his interest in science and research. Similar comments have been echoed by many scientists about their parents and old school friends.

Unlike many scientists who go to prestigious universities like Harvard, Oxford, and Cal Tech, Linus went to his local “cow” college, Oregon State Agricultural College (now Oregon State University). He majored in chemical engineering. He supported himself by working at all sorts of jobs. He chopped wood, butchered cattle, and mopped floors for a quarter an hour. He even provided much of his family's financial support. The college courses were not very challenging for Linus. He took the most difficult courses they had and still found time to join a fraternity, participate in varsity track, and work 25 hours a week.

In the summer, Linus worked as a paving inspector, checking the blacktop and later analyzing it in the lab. This work yielded $125 per month and stimulated his interest in chemistry. He sent this money to his mother to place in the bank for him to use to return to school for the fall term. However, when it came time to go back to school, Linus discovered that his mother had become ill and had spent all the money. But, he was such a good student that the college gave him a job helping to teach. At age 18, he was teaching the sophomore class that he had taken the year before.



Think About It!

In your notebook, state:

- **Personal traits of Linus that were similar to your own.**
- **Several childhood influences that probably helped Linus become interested in science.**
- **Personal traits he young Linus that you admire.**

In the fall of his senior year, Linus met the girl of his dreams. She was a home economics major taking the chemistry class he was teaching. He met her by calling out the simplest name on the class roster: "Miss Miller, will you please tell us what you know about ammonium hydroxide?" Miss Miller, it turned out, knew quite a bit about ammonium hydroxide, and it did not take long for her to know about Linus. In a few months, they became engaged.

When he graduated, Linus' mother wanted him to come home and make money, perhaps as a secondary school teacher. However, from reading some of the textbooks in college, Linus realized that he wanted to do research. His abilities and test scores were good enough to get him admitted to a PhD program at Caltech (California Institute of Technology). He obtained his PhD at age 24.

After graduation as a chemical engineer, Linus went to Europe for three years to conduct research in laboratories that were at the cutting edge of research on atomic structure. He then went back to Cal Tech as a faculty member. He was already a science superstar. He rose to the rank of full professor in only three years.

Linus became interested in atomic bonding. Soon, he was the leading authority. In the same year in which he was promoted to professor, Pauling published the paper that made him famous: "The Nature of the Chemical Bond." At age 32, Linus became the youngest person ever to be admitted to the U.S. the National Academy of Science. Pauling explained how atoms share electrons and how this sharing formed a bond to make a molecule. This work was the basis for Linus receiving the Nobel Prize in chemistry in 1954.

Linus showed scientists how to study how atoms bind together to form molecules. He discovered ways to measure the angles, bond energies, and distances between the atoms in a molecule. One of his key ideas was to make a "footprint" of the structure of molecules from the pattern formed by a stream of x-rays as it passes between atoms in the molecules of a sample. The technique is called x-ray diffraction. Atoms in a molecule affect the path of the x-rays in such a way that the pattern reveals the inner structure of the molecule.

Figure 2. Linus Pauling’s x-ray apparatus.

Pauling pioneered discoveries of the hydrogen bond. He showed that that in water hydrogen holds on to the oxygen atom by sharing its sole electron with an electron of oxygen. Hydrogen can form lose and easily breakable bonds with some other atoms, like those that hold DNA chains together.

Linus showed how molecules participate in chemical reactions, how magnetic fields affect molecules, how atoms attract extra electrons, and how atoms obtain electrically negative and positive regions.

Think About It!

In your notebook, state:

- **Explain how x-rays can cause a “footprint” of the position of atoms in a molecule.**
- **Can you figure out how hydrogen bonds help water to attach loosely to other atoms? Hint: think in terms of electrical fields of attraction. Oxygen protons pull in the electron of hydrogen. This separates hydrogen’s proton, making that part of the atom electrically positive.**

Early on, Linus' main interest was on how chemical bonds create the structure of proteins. He knew that the structure of any given protein depended on its environment. For example, consider the egg-white protein of eggs. When you break a fresh egg, do you see any whiteness? No. But when it starts to fry, all but the yolk turns white. What is happening here? The answer is that heat breaks certain bonds to change the structure so that it reflects a white color to your eyes. This process is called "denaturation," that is, the natural structure of the protein is changed.

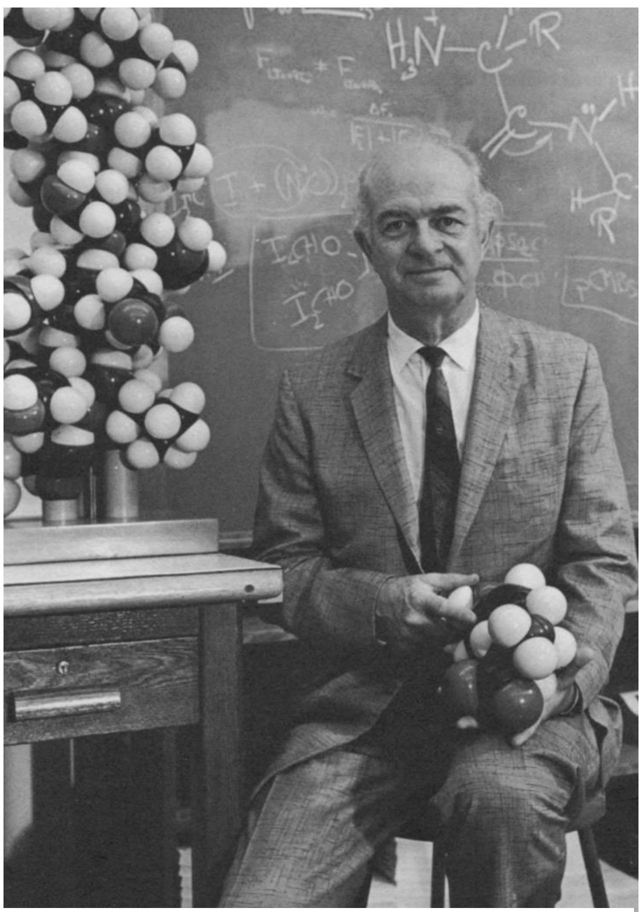


Figure 2. Linus Pauling worked with ball-and-stick models of atoms to illustrate the three-dimensional structure of molecules.

Proteins interested Pauling also because they controlled most everything happening inside the cell. Linus knew that enzymes attached in very specific ways to influence chemical reactions either to join molecules together or break them apart.

Proteins are even involved in the function of genes. Other kinds of proteins are anchored in eukaryotic cell membranes and influence cell-to-cell interactions. (Note: The Real Research Review on concussion deals with the proteins that keep nerve cells stuck together so they can communicate with each other).

In 1951, Pauling explained how proteins form complex three-dimensional structure in water. Other investigators had shown that proteins contained chains of amino acids bonded together. Think of it like a string of beads, with some strings attached to other strings by sulphur bonds (S in Figure 4).

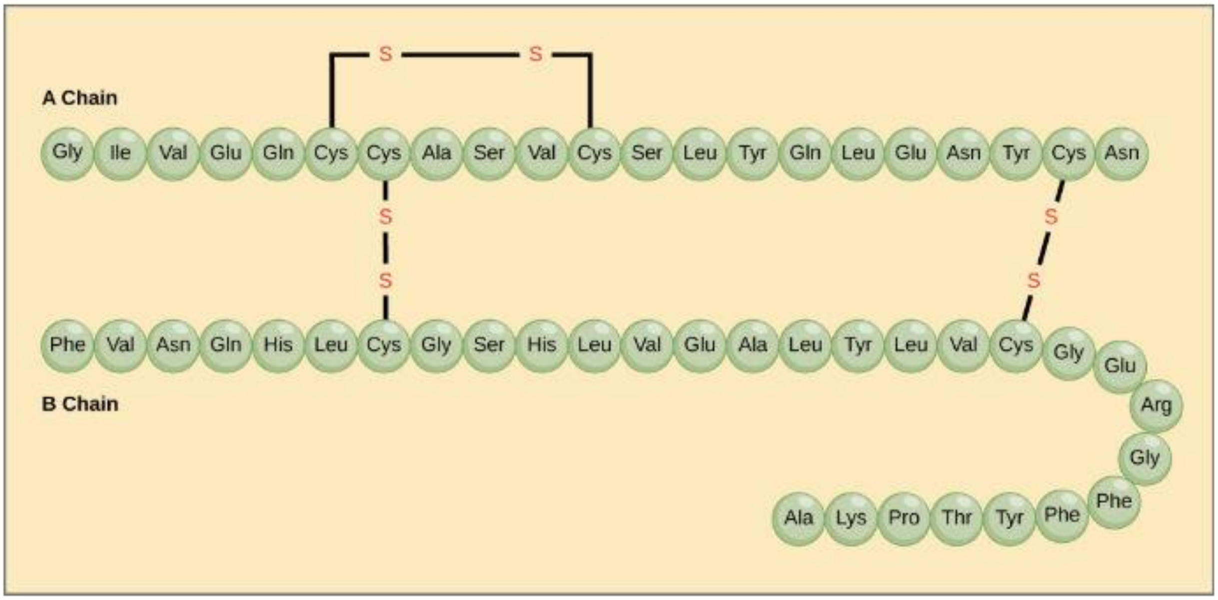


image credit: OpenStax Biology.

Figure 4. Components of a protein. All proteins are made of many amino acids (shown here with abbreviated names) linked together in a chain. Some of the amino acids in one chain get tied with amino acids in another chain by sharing bonds with sulfur atoms (S).

Linus and a colleague, Robert Corey, showed how the amino acids were constructed. They showed was that the hydrogen atom in one amino acid would form a weak bond with another amino acid four positions away in the chain. This bonding twists the chain into a coil, like a coiled telephone wire. The twist is right to left, creating a secondary structure that is called an alpha helix (Figure 5).

A further change in three-dimensional structure is imposed when sections of a coil line up against each other to form sheet-like structure. Finally, a third-level of structure is imposed when certain amino acids that are electrically charged and others that lack a charge cause stacking and folding to create a glob-like structure (Figure 5). The three-dimensional structure has pockets and protrusions of various surface electrical charges that govern how the protein interacts with other molecules. This complex structure dictates how that hormones, neurosecretions, and drugs act on cells, by binding at specific locations in the protein.

Figure 5. Linus showed that hydrogen bonds force amino acid chains to coil like a telephone cord. These then fold upon each other to form a glob surround by water and other chemicals.

Figure 5. Folding and stacking to create tertiary structure.

Think About It!

In your notebook, state:

- **Explain how Linus used his understanding of hydrogen bonds to figure out three-dimensional structures of proteins in water.**
- **Explain why three-dimensional structure affects how molecules interact with each other. Hint: think of how 3-D structure affects the access that molecules have to each other, like a hand in a glove. If the atoms get close enough to each other they can form bonds.**

These monumental discoveries were not enough for Pauling. He almost discovered the structure of DNA. Linus took on the challenge from a British team consisting of James Watson and Francis Crick. All of them used Pauling's bond-length data and ideas of coiling induced by hydrogen bonding and the approach of x-ray diffraction to decode the structure of DNA. The problem for Linus was that his resounding success with protein structure made him too optimistic about his prowess for solving the DNA problem. In a few months he dashed off his conclusion that DNA was a triple helix—a serious mistake. He apparently forgot that it took him some 15 years to unravel protein structure. He would not have made this mistake if he had seen the DNA x-rays that the British group had. He had asked to see them, but they would not share their pictures with him.

In their famous book, *The Double Helix*, Watson and Crick describe the race to be the first to understand DNA structure and, in the process, genes. They freely admit that the race was with Linus, and they used his explanation of chemical bonding as the basis for arriving at the correct structure of DNA.

One reason for Linus Pauling's lifetime of success is explained by an exchange he had with a high school student: "How do you get so many great ideas?" the student asked. Linus replied, "To get good ideas, the important thing is to have lots of ideas." He believed that if you were wrong, some smart scientist would soon show the idea to be wrong. This, of course, happened to him, because he was wrong about the structure of DNA. But if you are right, you may have an idea that nobody else would have thought of. Pauling got that right for hydrogen bonding and protein structure.

Author: W. R. Klemm

Photos:

The Double Helix, 1968, New York: Authenum (Linus Pauling, p.37)

Discover Magazine, Nov. 2018 (protein structures, p. 57)

Oregon State University, http://scarc.library.oregonstate.edu/coll/pauling/bond/pictures/1925i.63.html (Pauling lab).