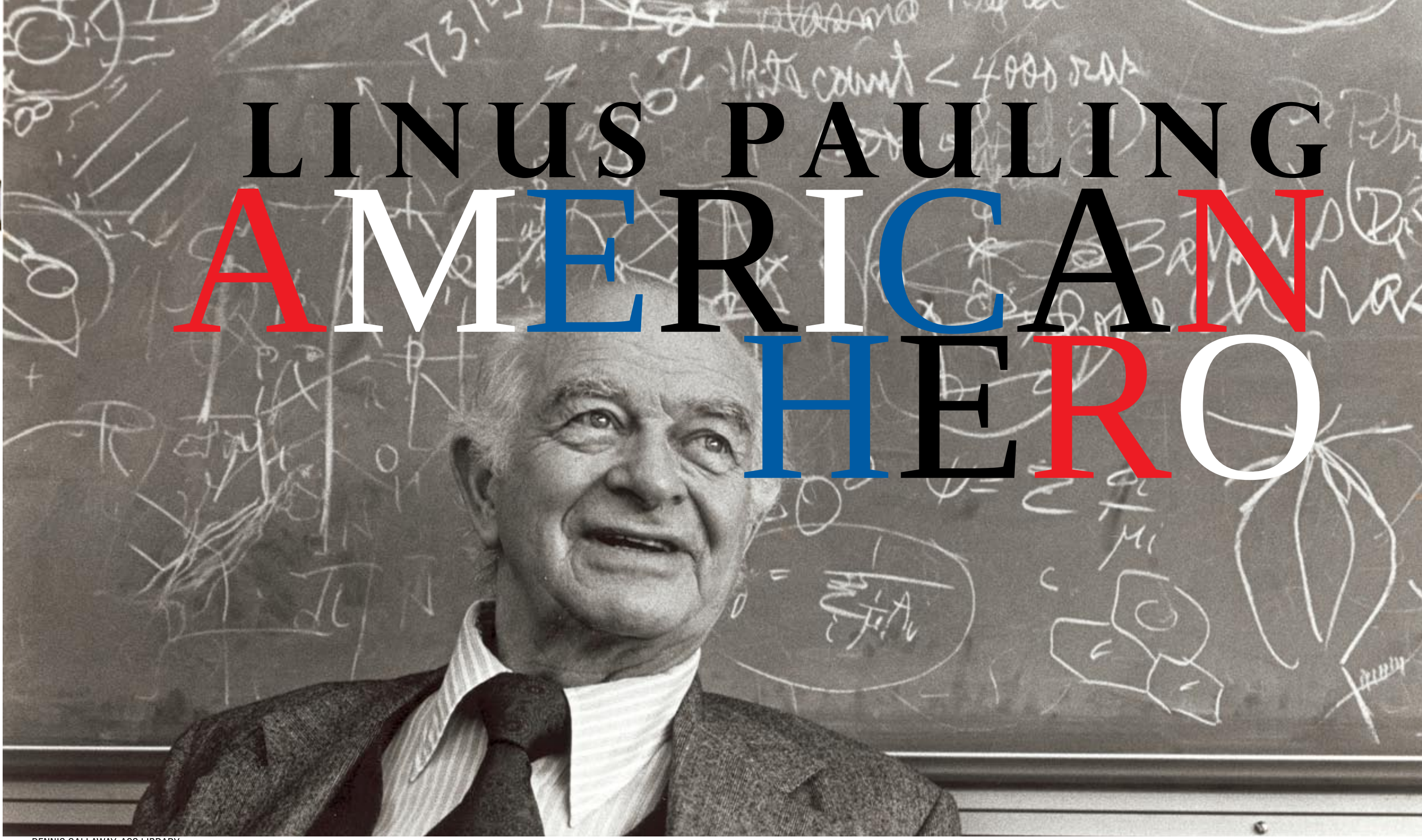
LINUS PAULING
AMERICAN HERO



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Talk to career chemists about how they got interested in the field, and chances are you'll hear something like this: ***"My friends and I had this chemistry set. We set up a lab in the basement with equipment we made or scavenged. There were a couple of explosions … minor of course … got in trouble with our parents …."***

And on the stories go. Linus Pauling would tell us just such a story. That's THE Linus Pauling who won two Nobel Prizes, one for chemistry and one for peace.

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By Sarah Vos

When Linus Pauling was 13, his best friend had a toy chemistry set. Pauling recalled watching a simple manipulation that involved boiling water over an alcohol lamp—and Pauling went home to read about it. Soon, he had his own chemistry lab in the basement of his mother's boarding house in Portland, OR. He scavenged equipment and chemicals from pharmacist friends of his father and from an old iron smelter lab. By one account, he and his friend Lloyd Jeffress soon learned how to combine chemicals to make small explosions; once they set off a loud one off under a trolley, scaring neighbors.

Early years

Pauling was born in 1901. His father, a self-taught pharmacist, died when Pauling was 9. His mother ran a boarding house to support herself and her three children. Money was short, and Pauling worked odd jobs to help out.

By the time Pauling took his first chemistry class at Portland's Washington High

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College Costs in 1920

According to the 1919/20 Oregon Agricultural College catalog, tuition was free to all students, regardless of place of residence.

Regular college fees were as follows:

Entrance fee, payable on registration	***$5 annually***
Incidental student fee	***$3.35 per term***
Gymnasium fee	***$1 per term***
Diploma fee on graduation	***$5***
Binding fee for graduation thesis	***$1***
Vocational certificate fee	***$1***

There were also lab fees and deposits charged on a per-term basis for science and other classes that included a lab component.

Dormitory room rent per term	***$18 single*** ***$9 double***
Board	***$4.50 per week***
Incidentals (laundry, etc.)	***$2 per term.***

School, he had already absorbed the basic rules that govern chemistry. His home laboratory experiences and the information he gathered from studying his father's books impressed his teacher. By the time he was ready to graduate, he knew he wanted to be a chemical engineer.

High school graduation had to wait—and wait! Because of a technicality, Pauling did not receive his high school diploma until 1962, long after he had received his bachelor's degree, doctorate degree, many honorary degrees from around the globe, and a Nobel Prize. Whoever said that high school graduation requirements are easy?

Despite his impressive record in chemistry, college was not an automatic option for Pauling. In the early 1920s, most boys went to work after high school to help support their families. Pauling's mother was barely surviving on the money she earned from the boarding house and her son's contributions from odd jobs. When Pauling got an offer of a good-paying job at a machine shop, his mother urged him to take it. In the end, he chose to enroll at Oregon Agricultural College (now Oregon State University) in Corvallis.

Pauling impressed the professors with his knowledge of chemistry, and, by his junior year, he was teaching a class on general chemical principles and laboratory techniques. The paid position allowed Pauling to stay in school and to send money to his mother.

After graduating from college, Pauling went to the California Institute of Technology (Caltech), to earn a Ph.D. in chemistry. That's where he started studying chemical bonds—the research focus for which he is best known.

Nature of the chemical bond

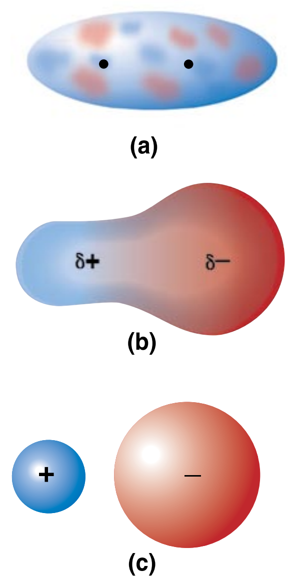
In college, Pauling learned and taught the most current and widely accepted model of chemical bonding—*the hook and eye model*—a name borrowed from the clothing fasteners used at the time. This model proposed that chemical bonds form when the *hook* of one atom connects with the *eye* of another atom. Different atoms had different numbers of hooks and eyes, thus dictating the number of bonds that an atom could form.

For Pauling, the hook and eye model raised more questions than it answered. Why do some atoms like carbon tend to form up to four bonds with other atoms, while other atoms like hydrogen form just one bond? What holds the bonded atoms together? Do the properties of bonds differ on the basis of the elements involved? How does bonding influence structure?

Pauling continued to seek answers to these questions as a graduate student at Caltech, as a Guggenheim Fellow in Europe, and, later, upon returning to Caltech as a professor.

All the while he looked for answers, Pauling made one significant contribution after another to scientists' understanding of the nature of the chemical bond.

As Pauling looked for his answers, many scientists still viewed chemical bonding based on two extreme definitions: one for covalent bonding and the other for ionic bonding. According to Pauling's contemporary Gilbert N. Lewis, a covalent bond resulted from the sharing of a pair of electrons equally. In an ionic bond, one atom "pulls" so strongly on the electrons that it removes the electrons completely, result-



(a) Covalent bonds result from the sharing of a pair of electrons by two atoms.
(b) Polar covalent bonds (bonds with some ionic character) result from the uneven sharing of electrons by two atoms.
(c) Ionic bonds result from one atom so strongly attracting the electrons of another that it removes those electrons, resulting in a negatively charged atom (anion) and a positively charged atom (cation).

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Fellow chemist Choh Hao Li with Linus Pauling.

ing in a negative charge on one atom and a positive charge on the other. The attraction of the negatively charged atom (the anion) for the positively charged atom (called a cation) forms the basis of the ionic bond.

However, Pauling and some of his contemporaries, including Lewis, questioned whether these extreme definitions were accurate or whether bonding could be viewed on a scale or *continuum*. At one end of the continuum would be covalent bonding and, at the other end, ionic bonding. They wondered whether bonds might be described somewhere in between the two extremes, with properties of both kinds of bonding. On the basis of experimental data, Pauling confirmed that bonds could be ionic, covalent, and, for those in between, exhibit a degree of ionic character. He theorized that the major determining factor was how strongly the atoms in the bond attracted the electrons. Pauling called this factor ***electronegativity***—the tendency of an atom to attract electrons in a bond.

Pauling assigned electronegativity values to elements based on their attraction for electrons in a bond. Fluorine, with one of the strongest tendencies to attract electrons, was assigned an electronegativity value of 4; sodium, with a very low tendency to attract electrons in a bond, was assigned an electronegativity value of 0.9. The magnitude of the difference in electronegativity values between two elements could then be used to determine the ionic and/or covalent nature of the bond.

Known today as the Pauling Electronegativity Scale, this scale of electronegativity values is used by chemists all over the world to predict the nature of bonds between atoms, especially when experimental evidence is not available.

As new knowledge and technology became available, such as new theories in quantum mechanics and X-ray crystallography, Pauling continued to fine-tune his explanations for molecular and crystal structure. Pauling developed a set of rules that bear his name to help scientists map the structures of ionic and covalent crystals. In 1939, Pauling put his ideas together in a work called *The Nature of the Chemical Bond*. The book is widely considered to be one of the most influential chemistry works ever written.

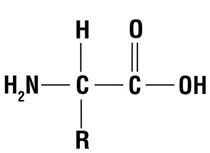
Proteins

Pauling turned his attention to proteins in the mid-1930s. Proteins, found in all living things, are large molecules. Proteins are actually chains of amino acids, small organic molecules consisting of an amino group ($–NH_2$), a carboxyl group (–COO), and a variable side group (commonly represented as *R)*.

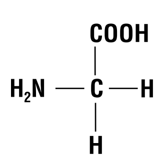
Using the same methods, he brought to study chemical bonds—diagrams, X-ray crystallography, and his set of rules for describing bonds—Pauling unraveled the basic structure of proteins. His work helped establish the field of molecular biology.

Pauling started by looking at the denaturation of proteins. Denaturation is the change of a protein's shape caused by factors such as heat, changes in pH, or high concentration of salts. Boil an egg, and you'll see denaturation at work. The liquid albumen or egg white protein readily solidifies upon heating. The result of denaturation may be a change in the properties of the protein. In some cases, denaturation is reversible; in other cases, it isn't.

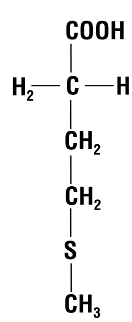
Pauling's study of factors influencing the denaturation of proteins led to an increased understanding of the different types of weak interactions that give proteins their shapes.



Monomer amino acid

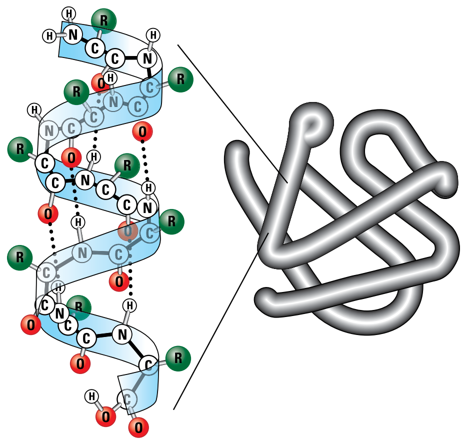


Glycine



Methionine

Amino acids are the building blocks of proteins. All amino acids have the same basic structure indicated by the generic amino acid at left. They differ based on "R" which can be very simple as in glycine (where R is a H atom) or more complex as in methionine (where R is $CH_2CH_2SCH_3$).



Linus Pauling is well known for his work with proteins. The alpha helix, at left, is one of the most fundamental structures of proteins. It is formed through a number of weak interactions between groups at different places along the protein chain. The folded structure is shown at right.

His work with protein chemistry soon led to his discovery and explanation of one of the fundamental structures of protein molecules—the alpha helix. The alpha helix resembles a spring. It is formed when the N-H group of one amino acid is weakly attracted to a C=O group of an amino acid several units down the chain. This type of weak interaction

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Linus Pauling recieves Priestly Medal from Warren Niederhauser.

is called hydrogen bonding. The helix shape allows many of these types of weak bonds to form, thus twisting the protein chain into a spiral.

Pauling's research interests also included the study of hemoglobin, a protein found in red blood cells essential for the transport of oxygen throughout the human body. Hemoglobin exhibits abnormal properties in people suffering from sickle cell anemia, a genetic blood disorder. Pauling demonstrated that the hemoglobin molecule changes shape when it gains or loses an oxygen atom. Pauling, along

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Linus Pauling receives the National Medal of Science from President Gerald Ford in 1975.

with, Harvey Itano, S. J. Singer, and Ibert Wells, discovered that the abnormal shape change that occurs in people with sickle cell anemia was due to a mutation in their DNA. This was the first demonstration that a change in a specific protein was associated with a human disease, thus foreshadowing a revolution in molecular genetics.

Pauling became interested in the effectiveness of vitamin C and other nutrients in treating and preventing a variety of illnesses. He worked, not entirely successfully, to convince the medical establishment of the benefits of certain vitamins, especially C, as dietary supplements.

Pauling received the Nobel Prize in Chemistry in 1954 from the Royal Swedish Academy of Sciences. This prize acknowledged and honored his work on the nature of the chemical bond and his application of this knowledge to understanding the chemistry of macromolecules such as proteins.

Pauling for peace

Working against the backdrop of World War II, Pauling was in favor of United States going to war against the Axis forces of Germany, Japan, and Italy. He contributed his scientific expertise to the National Defense Research Commission and the Research Board for National Security. But when he was invited to participate in the Manhattan Project, in which scientists developed the atomic bomb, he declined—not over any objections to the technology, but because he didn't want to move his family. But when the United States dropped two atomic bombs on Japan, Pauling began to question the use of atomic weapons.

Pauling challenged the U.S. government, arguing that the health consequences of radioactive fallout from the atomic bomb were far greater than the government acknowledged. Although the government argued that the increase of background radiation from nuclear bombs had only a small chance of affecting an individual, Pauling looked at the effect on the entire population. If, he argued, 1.5 million birth defects were caused each year by background radiation, a 1% increase would mean 15,000 more babies born with birth defects every year.

Pauling made speeches, participated in demonstrations, and wrote a book called, *No More War!* Unfortunately, his antiwar protests at this time in history made Pauling the subject of intense scrutiny. Pauling's anti-war activity coincided with the Cold War,

When he and his wife were invited to dinner at the White House with then President John F. Kennedy, Pauling spent the day before the dinner protesting outside the White House. He held a sign that said, "Mr. Kennedy … We have no right to test."

a time when fear of the Soviet Union was at its peak, and individuals who spoke out against the U.S. government and its actions were often considered to be anti-American. The FBI investigated Pauling to see whether he was a member of the Communist Party (he wasn't). His requests for a passport were repeatedly denied, so he couldn't travel abroad. By losing his security clearance, he lost research grants for his work. A pharmaceutical company for whom he did consulting work even fired him.

But Pauling didn't stop. In 1957, working with his wife from their kitchen table, he started a petition to stop the testing of nuclear bombs. Eleven thousand scientists from around the world signed it, and Pauling presented it to the United Nations. The petition helped change public opinion. When he and his wife were invited to dinner at the White House with then President John F. Kennedy—because he had won the Nobel Prize for Chemistry—Pauling spent the day before the dinner protesting outside the White House. He held a sign that said, "Mr. Kennedy …We have no **right** to test."

In 1963, the United States and the Soviet Union signed the first test ban treaty. That same year, Pauling was awarded the Nobel Prize for Peace.

Post-Nobel Prize

Following his acceptance of the Nobel Prize for Peace, Pauling worked for a number of organizations in California, continuing to pursue his passion for understanding the nature of genetic disease. He started his own research institute in 1973, currently called the Linus Pauling Institute (located on the campus of Oregon State University), where he continued to search for ways to understand and treat molecular disease until his death in 1994.

Pauling's prolific career included significant contributions to chemistry, molecular biology, biochemistry, and humanitarianism. It is easy to understand, given his accomplishments and high honors, why Pauling's story intrigues and inspires, even today. Identifying someone as a genius tends to be a bit overworked, but if there is anyone in the 20th century who demonstrated the exceptional ability and creativity associated with genius, it would have to be Linus Carl Pauling.

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