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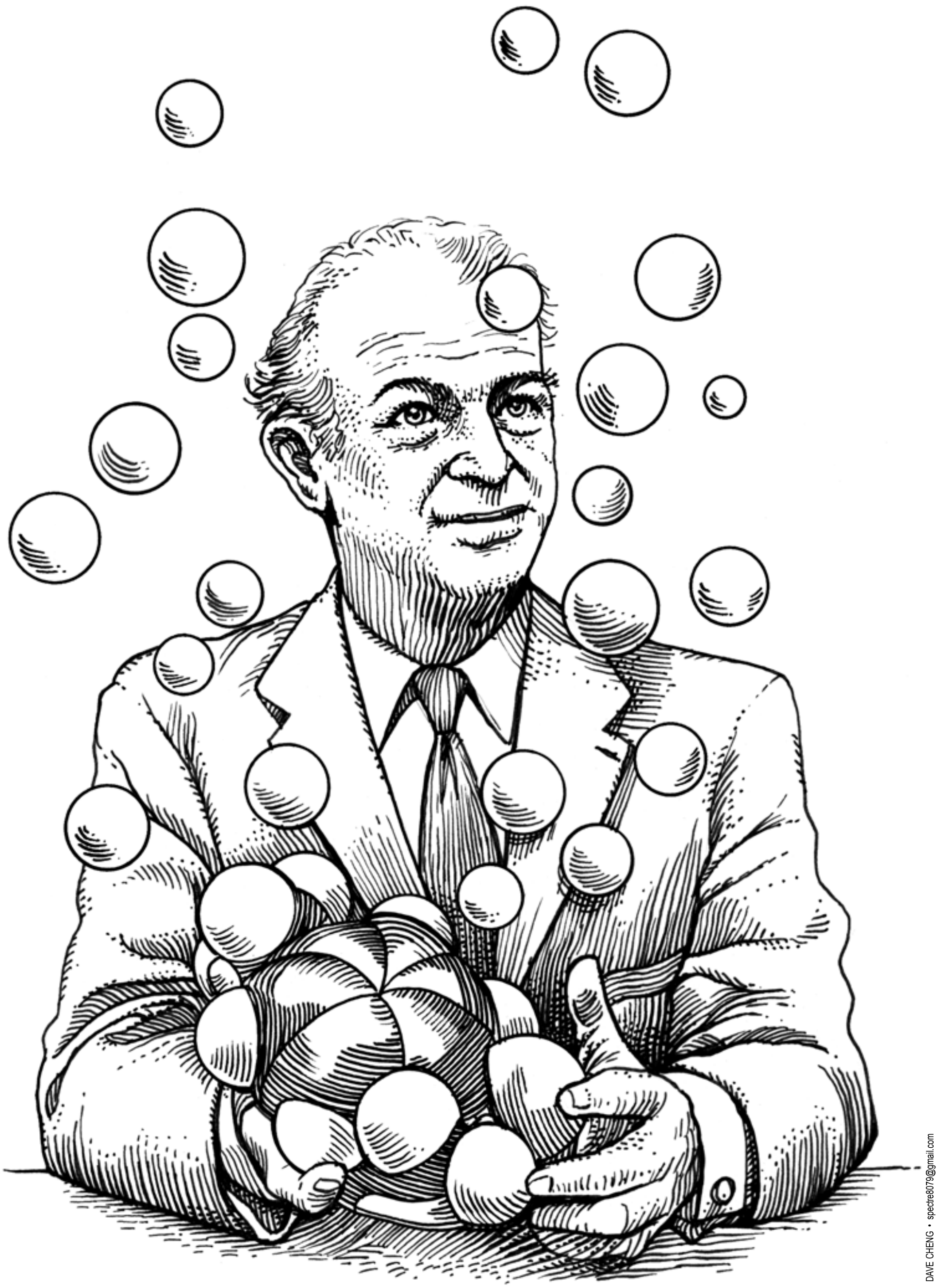

The Man Who Thought of Everything

Algis Valiunas

There are no scientists any more. Of course there are more persons than ever before who practice one scientific discipline or another, but they do not call themselves scientists plain and simple. To do so would offend against the clannish pride in expertise that is so often a hallmark of modern intellectual endeavor in just about any field you can name. Specialties and sub-specialties are abundant and scrupulously differentiated. One does not expect a cosmologist to have as much as a passing acquaintance with paleobotany. For that matter, a particle physicist adept in string theory might have difficulty making conversation with an acolyte of eternal recurrence; after their common undergraduate immersion in introductory physics, these experts pursued divergent professional paths and now speed ever faster and farther away from each other, as the universe of knowledge, and especially of the most abstruse theories, expands at an ever increasing rate.

For Plato the most sublime form of eros was philosophical friends' sharing the same exquisite thought at the same moment; for today's scientist, the most glorious proof of his wizardry is that when he is at the top of his game almost no one else in the world has any idea of what he is talking about. This rarefied collegiality might be considered the modern incarnation of Platonic friendship; it is in fact something very different. Esoteric knowledge has always been the surest sign of initiation into the mysteries, whether in religion or philosophy. Now it is the preserve of intellect at its farthest extension—often limited to an insistent probing of one particular question or problem, to the exclusion of much else that goes on in the world.

There are exceptions, and they are remarkable—perhaps none more so than Linus Pauling (1901–1994). Thomas Hager, in *Force of Nature: The Life of Linus Pauling* (1995), establishes his man's cardinal virtue and guiding passion with the opening sentence: "He could see everything from here."

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Seeing everything was to be Pauling's specialty, the ability that distinguished him from most of the acknowledged masters: he would make his name in chemistry, physics, molecular biology, wartime technological innovation, and anti-war activism. In *Linus Pauling: A Life in Science and Politics* (1995), Ted Goertzel and Ben Goertzel write, "Perhaps more than that of any other modern scientist, Pauling's work spanned all the levels of physical reality, from the submicroscopic world of elementary particles to the macroscopic world of living organisms." He was the only person ever to be awarded two unshared Nobel Prizes. But he is perhaps most often remembered as one of the founders of today's industry of dietary supplements for wellness, and as the outspoken advocate of vitamin C as the cure for whatever ails you. Those who knew him best knew him as the man who was sure he was right, even when he was not, and who more than once convinced others through sheer excess of confidence.

Becoming a Chemist

Seeing everything was Pauling's aspiration from an early age. Hager's account begins with a fifteen-year-old Linus Carl Pauling climbing a rusted ladder to the top of the eighty-foot smokestack of an abandoned smelting plant, from which he could survey the Willamette River Valley of his native Oregon, and the foothills of the Cascades rising to Mount Hood, solitary and superb in the distance. "He liked the sense of seeing how things fit and of being where no one else came, and he loved the height and the wind—and the sense of danger." His grandfather was the night watchman at the smelter, and he gave Linus the run of the place, where the boy ferreted out a treasure trove: an ore-assaying laboratory, whose contents he appropriated as his own by right of salvage and in the interest of science, packing his suitcase with apparatus and chemicals, once clutching five gallons of nitric acid on the train ride home, later enlisting a friend to help manhandle the richest prize of all, an electric furnace, down to the river, load it onto a canoe, transport it to Portland, and finish the job with a miles-long wheelbarrow ride down the homestretch.

Home was the hell one associates more commonly with the suffocating youth of cursed poets than with the upbringing of embryonic scientific masterminds. Pauling's beloved father, a drugstore owner with little education and mixed luck at business, had done his best to nurture his son's amazing boyhood craving for knowledge, especially of ancient history and of natural history. But Herman Pauling died of stomach problems at thirty-three, when Linus was nine, and Linus's mother was as poisonous as Baudelaire's, scorning her son's intellectual needs, measuring his worth exclusively by the money he earned for her with odd jobs, determined that he not waste his time by messing with college but rather make a permanent thing of the summer job he had in a machine shop, where any sensible person could see he had a real future.

Pauling was a mere boy and wanted to please his mother, but deep down he knew that to do so would destroy him. What saved him was his good fortune in friendship, which helped overcome his misfortune in family. When he was thirteen his pal Lloyd Jeffress suggested he take a detour on his way home from school and have a look at some chemical experiments in Lloyd's elementary lab. Linus went and watched and was hooked. At home he grabbed his late father's chemistry book and tore through it; he conducted his own maiden scientific demonstration, in which he boiled water with an alcohol lamp; he solicited donations of lab equipment and chemicals from a druggist friend of his father's and the stockroom clerk at the local dental college.

At fifteen Linus already knew he wanted to study chemistry and become a chemical engineer, since that was what he presumed chemists naturally did. When his grandmother asked him what he would be when he grew up, he answered accordingly. But Lloyd was there, and corrected him: Linus would not be an engineer, but a university professor. When the time came, it was Lloyd and Lloyd's aunt and uncle—Lloyd had lost his parents young—who entreated him to defy his mother's soul-killing demands and to go to college and become what he was meant to be.

It was some of the best advice he ever got. He did without a high school diploma, for he wanted to take the two American history classes required for graduation concurrently in his last term, but officialdom decreed they could only be taken consecutively; so Pauling shrugged at this patent stupidity and never looked back. In 1917, he enrolled at the only college he could afford, Oregon Agricultural College, a land-grant school in Corvallis, later to be called Oregon State University, neither before Pauling's day nor since a hotbed of intellectual adventure. There was no professor remotely of Pauling's mental caliber, as he was only too ready to let everyone know. The members of the chemistry faculty were not given to research, and they neglected to inform either their students or themselves about the extraordinary work done elsewhere; one year during Pauling's time there the only research seminar the department offered was on the business of frozen fish.

What Pauling could not learn in class he learned on his own. Classmates were awestruck at Pauling's powers of absorption and retention and combination. He aced his science and math courses with his eyes closed. For the first two years his classes were largely the same as those for mining engineers, so Pauling learned rather more than one would in most institutions of higher learning about dynamite and metalwork, even learning how to hammer a horseshoe out of a glowing hunk of iron. The most influential teacher Pauling had was the head of the chemical engineering program, Floyd Rowland, who Pauling said was not very smart but who had the sense to realize he wasn't. It was largely Rowland's doing, though, that of the dozen chemical engineering students in Pauling's year nine went to graduate school.

But during his freshman year Pauling also spent one hundred hours a month at menial work, to come up with tuition: he wielded an axe and a mop and a meat cleaver, at twenty-five cents an hour, to pay for the privilege of an education, and nobody appreciated more than he what a privilege it was. After his sophomore year, his mother informed him that he could no longer enjoy the privilege, because she needed the money he had earned for the next year's tuition to pay her outstanding expenses. He prepared to take a year off from school to earn the money he needed in order to continue.

But then the chemistry department offered him a job, at one hundred dollars a month, teaching the quantitative chemistry class he had just taken the previous year. He proved not only so solid but so fired up at the task that the department gave him more and more to do—including chemistry for the miners, who petitioned to have Pauling as their instructor, and for the home-economics majors. Among his home-ec students was a young woman named Ava Helen Miller, the smartest one in the class, so nicely made that no man in the room could miss her, and with a gift for seductive sass. What could Pauling do but decide to marry her, as he did in 1923—although he told her at one point that if he had to choose between her and science, he might not choose her.

Working as hard as he did, Pauling nevertheless had more time for himself than ever before. He romped joyously through the piles of chemistry journals that provided news of the scientific world far beyond Corvallis, and he ransacked the library stacks for unprofessional pleasures of variable seriousness, such as Maupassant and George Bernard Shaw and the *Saturday Evening Post.*

When he resumed his studies the next year, in 1920, there was no holding him back. He hungered for learning, and to be known as the smartest man in the room, wherever the room happened to be. The college nominated him for a Rhodes scholarship, but such trophies were not for the sons of Oregon Agricultural. That he was thrown out of the competition actually turned out to be a handsome piece of luck. Oxford might have taught its sons to compose passable dactylic hexameter in Attic Greek, but it was sadly lagging in the physical sciences. Pauling would not have learned there what he needed to know, as he later concluded.

There was a place in Pasadena, California that would meet his needs more than adequately. It was then a fledgling institution, but in time—and in no small part due to Pauling's presence—it would be renowned as perhaps the finest place in the world for students and faculty in the hard sciences. A professor at Oregon Agricultural happened to mention that the Throop Polytechnic Institute might just be Pauling's kind of school. Pauling wrote to inquire about finishing his undergraduate studies at Throop, but the cost would have made it impossible. When it came time for graduate work, however, Pauling passed over Harvard and Berkeley for the little-heralded school that had just changed its name from Throop to the California Institute of Technology. There were only three finished buildings on the Caltech campus, and a faculty of eighteen Ph.D.s supervised twenty-nine graduate students, of whom ten were chemists. It was no Harvard—but it was something better, where Pauling was concerned.

Fitting Pieces Together

Before Pauling's arrival at Caltech, three formidable men had been lured westward, from the University of Chicago and the Massachusetts Institute of Technology, by the opportunity to found a research institution unlike any other of the time: George Ellery Hale, the astronomer who founded the magnificent Mount Wilson Observatory in the early 1900s; Arthur Amos Noyes, the most famous American chemistry professor of the day; and Robert A. Millikan, the leading American physicist. Their aim as teachers was to break down the traditional divisions among scientific fields and to cast the most promising young minds in a new heroic mold. Hager writes that "in Pasadena chemists would regularly attend physics seminars; physicists would test theories of chemical evolution by looking out into space; astronomers would work with physicists and chemists to unlock the secrets of the stars." Caltech would be called a haven for geniuses, and the most impressive and important product of this new educational program would be the mind of Linus Pauling.

Perhaps no other school could have done as much for Pauling as Caltech did. Without question, he knew this was the place where he belonged, and where he discovered his life's work. All that had come before was kid stuff, the grunt work of math by rote and the endless repetition of lab demonstrations that had been repeated by countless others countless times before—a snap but a bore for an intelligence such as his. But here frustration with all those slow people who got in his way was over; everyone was smart enough and ambitious enough to hold his interest, even if no one else had quite his brainpower and drive.

Caltech was to be his proving ground. A. A. Noyes aimed Pauling's rocket mind in the direction it would follow for the rest of his career, a track into deep space that was his alone, soaring among the leading ideas in one field after another and discovering intellectual constellations where an incoherent scattering of stars had been before. Noyes and Pauling had corresponded before the school year started, and when Pauling could spare time from his summer job with a road-paving crew, he went about solving five hundred problems from the physical chemistry text that Noyes was writing. To memorize equations by the gross and plug the right ones into the assigned problems was the accepted pedagogical method, which Noyes found unacceptable: his students would learn how to derive the equations for themselves and thereby to uncover the mathematical basis for fundamental laws of physics and chemistry. Years later, Pauling would observe gratefully how Noyes's approach shaped his own.

Having seen something of Pauling's mental agility and his unshakable persistence, and having learned of his adolescent mineral collection and his passionate interest in the latest theory on chemical bonds, Noyes assigned Pauling to serve his doctoral apprenticeship under Roscoe G. Dickinson, a rising expert in X-ray crystallography. Since the discovery of X-rays in 1895, not only had they proven useful for helping to mend broken bones and dig out from the body potentially lethal pieces of shrapnel (an invaluable contribution to battlefield medicine in the Great War, spearheaded by Marie Curie), but they also pointed the direction for atomic physics. The German physicist Max von Laue and his enterprising students had found that an X-ray beam directed at a crystal of zinc sulfide would scatter and leave a diffraction pattern of light and dark spots on a photographic plate, clues to the atomic structure of that particular crystal. Laue was awarded a Nobel Prize in 1914 for his discovery, and the English physicists Sir Henry Bragg and his son Lawrence, who became the leading authorities on X-ray crystallography, shared another Nobel in 1915.

Here lay the future of atomic research. But the present still posed immense challenges, to do with crude equipment, fiendishly elaborate crystal structures, and torturous mathematical calculations in the bad old days when "computers" were still human. Hager, in *Force of Nature*, nailed with memorable brilliance the difficulty involved: "The whole process was something like trying to puzzle out the shape of a piece of ornate wrought iron by shooting it with a homemade shotgun and analyzing the ricochet pattern."

Pauling from the start was aching to prove his analytic prowess and to inscribe his name in the roll of honor—that is, to celebrate his authorship in an august professional journal. For two months he struggled to uncover or decode a crystalline structure—a structure never before taken apart, a publishable structure, with his everlasting name on it. He crystallized fifteen substances and got nowhere; the diabolical sodium dicadmide, as Hager points out with a sort of gleeful pity, happened to be utterly impervious to Pauling's analysis, consisting as it did of over a thousand atoms. (Only thirty-five years later would its structure be detailed, by one of Pauling's colleagues.) But at last, at Roscoe Dickinson's urging, Pauling tried the mineral molybdenite, made up of molybdenum and sulfur. Under Dickinson's painstaking direction, Pauling photographed thin slices of the crystal, and the two collaborators figured out the structure in a month.

Pauling had made his first mark and he wanted the world to know it. He wrote up the experimental results for his first publishable paper, and gave the article to Dickinson. Noyes presently asked Pauling in for a chat, and noted, gently enough, that the neophyte chemist had assumed sole authorship of the work, when in fact Professor Dickinson had been the guiding hand. Pauling got the point; the revised article appeared in the *Journal of the American Chemical Society* in 1923 with Dickinson's name ahead of Pauling's. Years later, Pauling would recall this incident as an important lesson in how much scientific work depends on collegiality. But it was not quite a lesson in humility—indeed, there were a good many occasions when Linus Pauling did not consider humility appropriate at all. In 1925 Pauling and Richard Tolman, Caltech's star professor of theoretical chemistry, coauthored a paper on thermodynamics and entropy, employing Tolman's particular skill with statistical mechanics. As Patrick Coffey tells the story in *Cathedrals of Science* (2008), Pauling demanded top billing, and Tolman conceded it to him; but the student's brash ambition and crass pushiness abraded the professor sufficiently that he refused to publish another article with Pauling, though they grew old and ever more distinguished together as leading lights on the Caltech faculty.

In any case, Pauling's first success made him crave more and more. He loved the work, and as Dickinson moved on to other things, Pauling became the resident expert in X-ray crystallography, teaching junior members as Dickinson had taught him, and racking up six more crystal structure readings, solo or in congress, as he labored toward his Ph.D.

This apprenticeship in crystallography prepared Pauling for a masterly career that would comprehend several gnawing mysteries under a common theme. With his customary lucid succinctness, Hager recognizes how Pauling's first years in the Caltech lab

> provided him with a new way of looking at the world. He spent so much time analyzing the depth, height, and width of crystal units, learning everything he could about the sizes of atoms and the lengths of the bonds between them, that from then on he would see everything chemical in terms of structure. Molecules, he began to understand viscerally, were built out of atoms, just as buildings were built out of bricks and beams. There was nothing random about their structure. They were connected at certain angles to make certain shapes; this was architecture at the scale of hundred-millionths of a centimeter.

Interlude: Crossing Disciplines

As Hager's description of Pauling's guiding insight suggests, genuine scientific understanding can be visceral, the rightness of a line of thought confirmed by some transcendent sensation. What Hager does not mention is that the natural resistance of established authority to an intellectual usurper can rage within as well. In science, tradition packs more authority than one might expect from the lovely modern fable that attributes unrelenting progress to vocational purity unequalled by any other profession: scientists, we are told, are endlessly open to the latest ideas, consumed by the need for the truth, undisturbed by the roiling petty ambitions that infect politicians and poets and all such lesser beings.

Patrick Coffey in *Cathedrals of Science* shows how the rare scientist who is "willing to be distracted from one line of research to pursue an unexpected observation," and who thereby opens a new line of research, can be met with disbelief shot through with enmity and contempt. Svante Arrhenius, a doctoral student in the early 1880s at Sweden's Uppsala University, was seeking entry to the guild of chemists devoted at the time to the unending project of synthesizing every possible compound, the work propelled by the synthesis of splendid dyes for the textile industry, which "changed the way the Western world dressed and decorated," and which made certain industrialists and their technological swamis very rich. The prevailing rigmarole failed to interest Arrhenius, who was thinking about "something on the borderline between chemistry and physics that would extend chemical theory." Defying the instructions of his dissertation advisers (one a physicist and the other a chemist, both apparently hidebound in their opposition to conjoining the two fields), Arrhenius set about investigating the electrical conductivity of solutions in relation to the molecular weight of the soluble substances. His mentors, or rather tormentors, lavished their revulsion on his work, and gave the dissertation the lowest possible passing grade, which disqualified Arrhenius from a university teaching position.

But Arrhenius impressed Wilhelm Ostwald, a German chemist in Riga, who was on a mission to "reform chemistry," as he put it—to understand the mechanism of chemical reaction, rather than to service the needs of industry. Ostwald's grand reformation of chemistry would seek to unify it with physics.

And among Ostwald's graduate students was the American Arthur Amos Noyes, who took his Ph.D. in Germany in 1890 before returning to teach at M.I.T., his alma mater. Noyes chafed at M.I.T.'s uncongenial emphasis on industrial know-how, but nevertheless used that know-how to invent a process for recovering solvents from photographic paper and reusing them, which saved manufacturers a great deal of money, and which also made Noyes a great deal of money. He used the cash to set up his own laboratory, where he could do pure research and renounce all concern with grubby industrial matters. When he went off to Caltech, he helped make it the ideal incubator for intellectual daring across disciplines previously kept strictly apart—just the spot for Linus Pauling.

Arrhenius to Ostwald to Noyes to Pauling: this fortuitous quartet opened a series of new scientific possibilities and launched lines of inquiry that brought together chemistry, physics, and biology at the highest levels of investigation. The course of science, and consequently of modern life at large, could have come out quite differently.

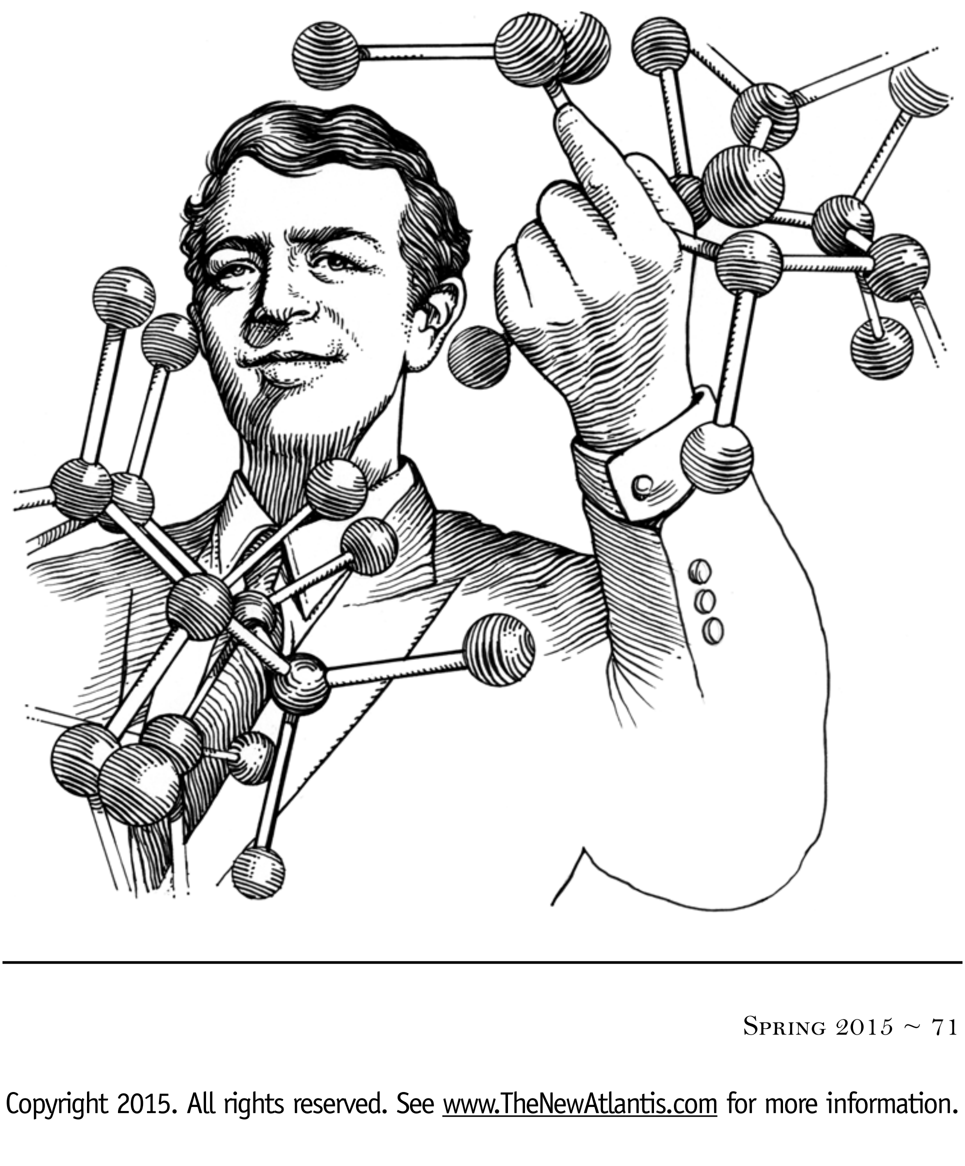
Knowledge, Intuition, and Theories

In Pauling's first year at Caltech, a professor asked Pauling a question that he could not answer, and he replied that he didn't know because he hadn't taken the relevant course yet. The professor frowned and went on. A postdoctoral fellow took Pauling aside after class and told him, "You are a graduate student now, and you're supposed to know everything." Pauling took this advice to heart. Omniscience is a tough skill to acquire, but Pauling set about stocking his mind with all the knowledge Caltech and the larger scientific world had to offer. His coursework included mathematical physics, physical chemistry, advanced algebra, higher dynamics, thermodynamics, chemical thermodynamics, advanced thermodynamics, kinetic theory, vector analysis, Newtonian potential theory, quantum theory, physical optics and quantum theory, functions of a complex variable, integral equations, and a weekly chemical research conference. Firmly anchored in the mathematical necessities, which enabled him to be more than acquainted with the latest subatomic arcana, absorbing every available fact and theoretical innovation the chemistry faculty shot his way, and venturing far afield through the journal literature, Pauling readied himself for an onslaught on nothing less than science in his own exalted understanding of the word.

When Pauling conducted a 1931 Caltech seminar on the nature of chemical bonds in the light of quantum mechanics, Albert Einstein, who was in attendance, asked Pauling to elucidate a number of points, apologized for being so slow on the uptake, and afterwards told a reporter that it was too complicated for him. The *New York Times* quoted Einstein as saying, "I'm afraid I'm not up on the chemical bond" and "I shall have to brush up on the subject before taking more of your time." Even a mind preternaturally supple and expansive as Einstein's could be overwhelmed by the otherworldly peculiarity of the new physical chemistry, while a less acrobatic intelligence may simply miss the trapeze altogether and claw the air helplessly in the plunge toward mental pandemonium. Like much else in the bizarre novelty shop of miniaturized speculation, Pauling's great achievement, the hybridized bond, was only made possible by a drastic conceptual rejiggering. (The theory: A chemical bond will oscillate between ionic and covalent types, the former based on the electric attraction of the negatively charged atom for a positively charged atom, the latter on the sharing of electrons by different atoms; one must think of these two distinct chemical structures as existing simultaneously, in a state called "resonance.") Pauling himself once confessed that he left his calculations for a 1928 paper unpublished "because they just were so complicated that I didn't have confidence in them." He was only able to describe the whole wondrous improbability of how the new quantum physics applied to chemical bonds once he found, in a "eureka" moment, a simplified and readily soluble set of equations that fit his intuitive scheme.

Pauling's modus operandi in any case was to save the troublesome details for last. He favored a stochastic approach—setting forth a hypothetical solution to a problem and eliminating one by one all of the other possible solutions. More often than not, Pauling's plausible conjecture was really better than plausible, for it was sealed with the conviction of a mind so magnificently laden with knowledge and so sure-footed in the theoretical avalanche zones that there was little danger of some radical misstep. Pauling could envision the elaborate molecular framework with startling clarity. The annoying intricacies remained, the little facts that had to be gotten exactly right or the elegant structure would collapse: the precise angle of a particular bond, the length of another worked out to a nicety measured in ångstroms, hundred-millionths of a centimeter—not a lot of room for error.

But then theories of cogent beauty and beautiful cogency are made to be superseded by others finer still, more lovely or more precise or more useful or all three. Science seeks the whole truth, but when that remains unavailable, practitioners resort to closer and closer approximations, in the hope that the sanctum might one day be penetrated. Consider the case of the two competing theories that sought to explain how atoms bond together in molecules: Pauling's valence bond theory and the molecular orbital theory developed by Robert Sanderson Mulliken of the University of Chicago.



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The two theories were developed around the same time, starting in the late 1920s and early 1930s. For years, Pauling's rhetorical skill, as writer and lecturer and conversationalist, helped to hold Mulliken's theory at bay. Pauling's mind galloped and sang; Mulliken's plodded and muttered. Thomas Hager convicts Mulliken of being the supreme bore in a field with many contenders for the title. The theoretical model he proposed seemed outlandish to most chemists, and he multiplied the confusion by his miscreant notation, intelligible to specialists but not even to chemists in other fields, as one critic complained. As a teacher Mulliken was a dud, hemming and hawing and fatally smudging every line of argument, as though he himself could not be sure what he meant, and droning on and on until the last student left alive in the lecture hall put himself out of his misery.

Naturally, Mulliken resented Pauling's winning élan and argumentative vigor, and condemned him as a "showman" who dazzled the credulous masses—that sad benighted chemistry professoriate—with beguiling simplifications offensive to a mind that honored the harrowing complexity of honest science. Hager notes that by the late 1940s Pauling's and Mulliken's approaches "were at their core essentially the same"—with sufficient mathematical rigor, both provided the same results—but Mulliken's "had developed simpler and more useful tools for the quantitative study of molecules." The Mulliken version was nosing ahead in the application to large molecules, thanks to a host of painstaking followers clearing the underbrush. By the mid-1950s, Mulliken's molecular orbital theory had eroded the authority of Pauling's valence bond theory. Moreover, Mulliken's scheme happily lent itself to computerized solutions, which made it ever more agreeable to chemists in the 1970s and 1980s. Only in recent years has Pauling's approach seen a resurgence in acceptance and use.

In the end, neither Pauling nor Mulliken got the theory entirely right: the impossible exactitude required to solve the underlying quantum mechanical equations meant that neither theory could ever be perfect. In the Goertzels' summation, "both of these theories are just approximations to the real solutions of the equations of quantum mechanics, which remain intractable except for simple cases." To penetrate even such simple cases demands mental powers that ordinary persons cannot begin to summon, and the men who succeeded, even if only in a limited way, were not unjustified in admiring their exceptional tenacity and imaginative brilliance.

The Creation of Molecular Biology

When Pauling submitted to the *Journal of the American Chemical Society* his 1931 breakthrough article, "The Nature of the Chemical Bond," he thought, as he later told an interviewer, that the editor of the prestigious organ would be "buffaloed" in his search for a suitable referee: no other chemist possessed the requisite knowledge of quantum mechanics to judge Pauling's work; the peer-review process had to concede that in this area Pauling had no peer. The thirty-year-old Pauling had already done other impressive work, and the journal editor relied on the author's reliability: when the paper was published, very soon after submission, it opened new territory, presenting a novel approach to old questions and pointing a direction for future researchers to follow.

Most scientists are as susceptible to the need for recognition as artists, athletes, or politicians, and the love of fame—"that last infirmity of noble mind," in Milton's phrase—redoubled Pauling's pleasure in his achievement. He always treasured the satisfaction of knowing something about the way the world works that no one else knew yet, and he enjoyed just as much the admiration of others when his singular discoveries were brought to light. The American Chemical Society bestowed on Pauling its inaugural Langmuir Prize for the country's outstanding young chemical researcher. The president of the society told everyone listening that Pauling was *the* hot prospect, bound for superstardom, maybe for the Nobel Prize. The journalists may not have understood what the commotion was about, but they did love the commotion, and fed it extravagantly.

The principal aim of Pauling's scientific career would be to discern the underlying structure of all matter, and to understand how that structure, bordering on the infinitesimal, determines the substance, composition, and even the function of inanimate objects and living organisms alike. He sought the "secret of life," as he put it: reducing the simplest creature and the most complex to their irreducible elements, which are common not only to both amoeba and biochemist, but to plankton and poet, dandelion and dandruff, lizard and linguine. He was out to answer the sorts of questions that puzzle a wondering child, and that bedevil the parents and teachers whom the child badgers with his endless importunate curiosity: Why is stone hard and sand soft? What happens to water when it turns to ice, and how is this transformation possible? Why won't a length of rope stand up straight?

Biology at the cutting edge was no longer to study the creature in its native habitat, or even on the dissecting table. The mating habits of the river otter and the protective coloration of hummingbirds were the concern of the naturalist, who was a quaint relic of the amateur's heyday, at best little more than an inspired primitive, perhaps an artist at heart like Thoreau or Audubon. Such dabblers in the shallows have their place, but the real work is done by others. Minutiae, the smaller the better, assumed the commanding position in the new scheme of subjecting nature to examination. The serious biologist would henceforth be a molecular biologist. And molecular biology was the natural extension of the latest advances in chemistry and physics, which is to say the outgrowth of Linus Pauling's consuming master idea, with which he intended to enrich every college freshman's callow mind, and to haunt the dreams of his most accomplished colleagues, who could not hope to be as accomplished as he was. Oddly, though, to some extent that idea would be forced upon him by economic compulsion.

The term "molecular biology" was coined in 1938 by Warren Weaver, a sometime Caltech junior professor of physics who proved a wash-out in the laboratory but would become a world-historical strategist and recruiting agent for the Rockefeller Foundation, bankrolling talent for the exploration of "the unknown world inside isolated cells, the charting of metabolic pathways and the structure of individual proteins," as Hager puts it. Drawing on eugenic ideas then in vogue, Weaver sold the Rockefeller trustees on his project for "The Science of Man," which would at last subject the dicey and improbable social and political schemes for virtue and justice, all failures since time immemorial, to the control of supreme and entirely successful rationality; the minds that unlocked the intracellular mysteries would make human beings intelligible to themselves for the first time, and thus amenable to being made perfect, as their Father in the biochem lab is perfect. What did Aristotle know of happiness? What could fear of the Lord possibly have to do with wisdom? As the Rockefeller Foundation asked in its 1933 annual report,

> Can we obtain enough knowledge of the physiology and psychobiology of sex so that man can bring this aspect of his life under rational control?...Can we develop so sound and extensive a genetics that we can hope to breed in the future superior men?...In short, can we rationalize human behavior and create a new science of man?

The Rockefeller Foundation would seed the glorious future with largesse to deserving researchers—and henceforth, in order to be deserving, one must be dedicated to this new science of man; old-guard math, physics, and chemistry professors need not apply. Hager's sterling account of this project helps make his case that "the history of American science was also the history of politics and economics," and that "Pauling's life illustrates the importance of funding concerns, public relations, politics, and personality in the way scientific ideas are discovered and advanced."

For in 1933 Weaver had notified Pauling, whose work the Rockefeller Foundation had generously underwritten for several years, that the flow of cash, the life's blood of the laboratory, would be cut off unless Pauling focused his research on more biologically oriented topics. Pauling was studying the wrong subject; the vital action lay elsewhere. But Pauling's protean mind was eminently adaptable. As Hager puts it, "He followed the money." Yet the decision was not really so crass as that—or not simply so crass. Although Pauling had never even taken a single biology course, shifting his focus to the chemistry-biology connection seemed the natural next step in a grand design he was beginning to perceive, and to construct, as he went along: this was how science in the largest sense, the sense that so appealed to his imperial mind and character, was to be done. To think about proteins suited Pauling's taste for significance; he longed for a question of immense moment, answering which would make his name a historic one. As Hager writes, "Proteins were involved in every reaction and formed an important part of every major structural component of the body. If there was a secret of life, it was thought, that secret would be found among the proteins."

Protein molecules were a bear to tangle with, however, in large part because they ran to gargantuan size and ferocious complexity. But hemoglobin, the protein that carries oxygen inside red blood cells, was congenial to the researcher: it consists of a manageable number of components, including iron and oxygen, that seemed comprehensible when disassembled and put back together again. Here was a plausible line of attack, and a suitable project for the Rockefeller-sized ambition. Pauling observed that after he was awarded the grant money, "Warren Weaver then invented the phrase 'molecular biology' for what we were doing."

What Pauling initially wound up doing was to measure several aspects of the magnetic properties of hemoglobin and to determine how they were affected by the bonding of hemoglobin to oxygen. Success upon success lit up Pauling with mental energy, and he expanded his researches from the heme in hemoglobin to its globin or protein. Beginning with an empty belly once again, he swallowed the available literature like the hands-down champion in an all-you-can-eat contest. In particular he found the pioneering work in organic chemistry of Emil Fischer over thirty years before useful to launch his own physiological speculation: he sought to find out how the fundamental protein structure, a polypeptide chain of amino acids, licensed the manifold uses the human body had for proteins, and specifically for globular proteins, which were soluble in bodily fluids.

Still wanting in certain basic knowledge, and particularly short on actual experimental achievement, Pauling chased down a protein master from the Rockefeller Center for Medical Research, Alfred Mirsky, and arranged for him to spend a couple years at Caltech. Together Pauling and Mirsky worked on the denaturation of proteins and the possibility of reversing the process: with hemoglobin, for instance, first heating it into deformity and making it incapable of transporting oxygen, and then cooling it so that it recovered some of its original shape and other characteristics. Mirsky had earlier performed experiments that suggested there were two levels of protein denaturation, dependent on the severity of the ordeal to which the protein was subjected: mild heat, for example, might leave open the possibility of reversal, whereas extreme heat or exposure to certain chemicals would make the breakdown permanent. From this evidence Pauling teased out the structural implications: there seemed to be two different types of chemical bond in the protein, one weak enough that it might be both ruptured and healed with ease, the other sufficiently durable that it would be tough to break and impossible to make whole again. With his rare expertise in the nature of the hydrogen bond, Pauling raced to his conclusion: there were instances in which hydrogen was not limited to just one ionic or covalent bond, but could also form an "electrostatic bond" with another atom; these weaker bonds explained the degrees of denaturing in Mirsky's experiment. In Hager's description, "Slight heating broke the hydrogen bonds, allowing the chains to straighten out and tangle like loose yarn in a sewing box. As long as the chain remained in one piece, however, under the right conditions the hydrogen bonds could re-form and the protein could regain its original shape and activity. Stronger treatment would break the chain itself, severing peptide bonds and irreversibly denaturing the protein." A 1936 article in the *Proceedings of the National Academy of Sciences* established Pauling, a relative newcomer in a largely unexplored field, as an indispensable leader. Warren Weaver named molecular biology; Pauling was defining it.

Molecular Disease

Inevitably, Pauling began to speculate about medical implications of the work he was doing. In 1945 he would make a sudden leap from molecular biology to molecular medicine, when, at a government-sponsored dinner gathering of medical experts where only he was not a doctor, the subject of sickle-cell anemia came up and sent Pauling's mind into overdrive over coffee and dessert.

Dr. William B. Castle, a Harvard medical school professor, had described the miscreant red blood cells, twisted into sickles where normal cells were disc-shaped, and jamming small blood vessels to cause the sufferer severe bone pain or even deadly blood clots in major organs. The disease affected black people almost exclusively, so a genetic factor seemed prominent. In the rich source book *Linus Pauling in His Own Words* (1995), Pauling is quoted as being indifferent to the matter under discussion before becoming bemused all of a sudden:

> I did not pay much attention; cells seemed to me to be too complicated for me to be interested in. However, when he said that the cells are twisted out of shape only in the venous circulation, and regain their normal shape in the arterial circulation, I thought immediately: Why is it that this difference between the arterial and venous blood exists? It must be the hemoglobin, because in arterial blood the hemoglobin is oxygenated, and in the venous blood it is not oxygenated. These people must manufacture a different kind of hemoglobin from ordinary people.

The intellectual thrill of being onto something entirely new yet suddenly clear carried him into a promising line of inquiry.

> I remember the feeling of excitement when, during the few seconds after my friend, Dr. Castle, had talked about sickle-cell anemia, I thought that it might be possible that this disease is a disease of the hemoglobin molecule rather than of the red cells of the blood. Diseases of this sort may be called molecular diseases. By learning the molecular structure of the molecules that cause these diseases we can understand what the mechanisms of the diseases are, and possibly may develop drugs on the basis of this knowledge.

In the absence of oxygen in the venous blood, Pauling speculated, the sickle-cell hemoglobin would undergo a structural change that resulted in crystallization. And yet the Caltech researcher Harvey Itano, whom he enlisted to help him, found the hemoglobin of afflicted persons no different from that of healthy ones in size, molecular weight, and other essentials. Only when another postdoctoral fellow, John Singer, tested the hemoglobin with a new machine that registered the very subtle electric charges of proteins did the difference between sickle-cell and normal hemoglobin come to light: as Hager writes, "it looked as though at normal pH the sickle-cell molecule carried about three extra positive charges.... By pinpointing the source of a disease in the alteration of a specific molecule and firmly linking it to genetics, Pauling's group created a landmark in the history of both medicine and molecular biology." In a 1948 lecture, Pauling exclaimed triumphantly: "We do know what the nature of life is (aside from consciousness), in terms of molecular architecture, the atomic structure of the molecules that constitute living organisms."

The Great Blunder

Pauling's approach to understanding the nature of life involved the exploration of structure—studying, as Horace Freeland Judson writes in his invaluable account *The Eighth Day of Creation* (1979), "the physical configurations of the large, long-chain molecules of the cell, to characterize their chemical sequences exactly and to reconstruct their three-dimensional architecture." While Judson acknowledges that this structural research was "a British invention and a British specialty," Judson leaves no doubt that the nonpareil in this department was Linus Pauling, "who had energy, inventiveness, showmanship, and genius enough for a consortium."

But other researchers took a different path to understanding life. That path, as Judson puts it, lay "through the function of the gene," which was often investigated in bacteriophage viruses, very simple biological agents. When the twenty-three-year-old James D. Watson, schooled at the University of Chicago and Indiana University, arrived in 1951 at the Cavendish Laboratory in Cambridge, England, he came bearing the expertise in genetics of the American phage people, and intended to absorb the knowledge of chemical structure that Francis Crick and his clan possessed. The race to reveal the structure of DNA was on, in Watson's mind anyhow, and he believed his chief rival was Pauling.

By the early 1950s Pauling had been stalking the secret of life for a good long time. Ever since his early work on hemoglobin in the 1930s he had been thinking "more generally about the properties of the large molecules found in living organisms and about the problem of the structure of proteins," as Pauling recalled to Judson. English crystallographers were publishing amino acid studies without descriptions of structure and with X-ray diffraction reports that misinterpreted the structural patterns they recorded. Molecular biologist William Astbury believed that he had discovered the precise fit of DNA and protein in the chromosome, but Pauling's own measurements of bond lengths and angles in simple molecules told him Astbury was wrong about the spacing of repetitions in the coils of molecular structure. Pauling and his Caltech colleague Robert Corey labored from 1937 until 1948 to nail down numerous amino acid and peptide structures in order to convince themselves that the earlier work with simpler molecules hadn't led them astray. Confirmed in their basic suppositions, Pauling and Corey began constructing models out of wood, metal, and plastic to render the exact helical coils of the polypeptide chain that formed the protein. These were, as Judson writes,

> precisely scaled physical representations of the atoms—open three-dimensional puzzles in which the individual pieces to be fitted together already carried many of the limitations of angles, lengths, and sizes. These simple toys were one of Pauling's most remarkable contributions to molecular biology: they amounted to a kind of analogue computer that embodied many of the physical rules and restrictions, in order to cut out the endless refiguring of interlocking readjustments.

Pauling recollected in his 1954 Nobel Prize lecture that these models were conceived of necessity; "extensive numerical calculations" were the only alternative, and for exceedingly complex structures these were simply impossible. The models themselves had to be fabricated with great care; even very slight errors of angle or size would make them useless.

Working from their models, Pauling and Corey (joined sometimes by another former Caltech colleague, Herman Branson) published a series of articles in 1950 and 1951 describing proposed structures for hemoglobin and various other proteins found in substances ranging from hair to muscle to feathers. Their rivals at the Cavendish blazed with envy at Pauling's genius.

And yet in the end Watson and Crick got the epochal question right while Pauling got it wrong. In February 1953, Pauling and Corey's paper "A Proposed Structure for the Nucleic Acids" appeared in the *Proceedings of the National Academy of Sciences.* Basing their findings not on any experimental measurements of their own but rather on other researchers' data such as X-ray diffraction results, unreliable in themselves and their inadequacy grossly amplified by the great man's uncharacteristic mishandling, Pauling and Corey declared that they had cornered the elusive structure at last and that it was a triple helix. Pauling's misguided belief that his signature hydrogen bonds at the core made this structure possible became known as his signature scientific misstep. To place the hydrogen bonds where he did not only resulted in an ungainly construct so tight it creaked, it actually "made chemical nonsense," in Judson's words: Watson understood that magnesium, not hydrogen, was needed if the nucleic acid was to be an acid at all.

Watson, at least as competitive as Pauling, reports in his memoir *The Double Helix* (1968), that in his camp there was "pleasure that a giant had forgotten elementary college chemistry." Pauling is now as notorious for this blunder, which ultimately enabled Watson to win his Nobel Prize, as he is celebrated for his own Nobel Prize-winning work on the chemical bond. Pauling would say he had not really been concentrating on DNA as he usually did on the work in front of him; but perhaps he had been eyeing the prize rather than the work itself. Nevertheless, as Judson writes, "The discovery of the structure of DNA by James Watson and Francis Crick was itself a tribute—Crick's tribute—to Linus Pauling." Pauling and his molecular models pointed the way in, although he failed to understand just what he saw when he drew near to the mystery.

A Political Education

Pauling's was not only a scientific life; it became a political life as well. His is an all-American story. He was the proverbial young man in a hurry, and he worked as feverishly as he did not only for the thrill of knowing or the esteem of his colleagues but also to rise in the world in just the way that most men, and especially most Americans, understood that phrase: to ascend in social status and to secure material comfort and even to steal a taste of luxury, to make it and make it as big as he could as fast as he could. Young Pauling despised the coarseness and gaucherie of the milieu he grew up in: the Caltech roommate and longstanding friend who ate with his knife and failed to button his vest all the way up sent Linus into conniptions of disgust, as he wrote to his wife-to-be. The lack of breeding endemic to the lower middle class distressed him at least as much as the simple lack of money: "I shudder at the things they do," he wrote of this friend's family. (Late in life, this friend would marry Pauling's sister Pauline.)

A career in science offered a way up and out for many young men who were born into circumstances that failed to comport with their notion of natural rank. The climb took diligence and thrift, single-mindedness and patience: the reigning virtues of a commercial republic and emergent meritocracy. Patience was among the virtues that came hardest to Pauling. His preternatural mental quickness enabled him to race ahead much faster than the pack, and it seemed only just that his obvious superiority should be decked straightaway with all available prizes. But he learned that only hard work would get him what he wanted, and he knew early the pleasure of doing work he loved. So his reaching the heights he longed for came as no surprise, but was a rich satisfaction he knew he had rightly won.

With his belief that talent and the necessary effort will carry a man as far as he wishes, that in America one will have the life he makes for himself and therefore deserves, young Pauling was a patriot and a Republican born and bred. Not that he paid much attention to politics at first; unlike the natural philosophers of old, most scientists in the nineteenth and early twentieth century were apolitical animals, steering clear of entanglements with government. But the alarming extent to which scientific expertise enhanced the human capacity for murderousness would change that for many honorable men, as well as for numerous fools and scoundrels. It changed, too, in Pauling's case, thanks to the woman he married and cherished, and who saw the political world far differently than her unwitting young husband did.

It was inevitable that she would inspire a biography of her own, and Mina Carson's *Ava Helen Pauling: Partner, Activist, Visionary* (2013) offers exactly the sort of tribute one would expect from a right-thinking academic. Although Ava Helen was not by any stretch Linus's equal in his professional specialty, she was his invaluable preceptor in ethics and politics, and really the moral superior who fired him with the longing to be worthy of her, and to save the world while he was at it.

> Proud to be Linus Pauling's wife, lover, consultant, housekeeper, dietician, and co-parent, she also parlayed her intimacy with him into the status of change agent. She was the one who persuaded Linus that it wasn't enough to do brilliant chemistry if the world was tumbling toward annihilation. She coached one of the twentieth century's most gifted science teachers into teaching citizens about the linkages between atomic weaponry, health, and social justice.
>
> But Ava Helen Pauling had her own career as an activist first for civil rights and civil liberties, and then against nuclear testing, and finally for peace, feminism, and responsible stewardship of the environment.

Check, check, and check: all the requisite boxes for certifiable wisdom and decency are duly filled. And while the honorific *visionary* used to pertain to such figures as William Blake, Emanuel Swedenborg, and St. Teresa of Ávila, today simply to anticipate the several obligatory opinions of the American professoriate places a twentieth-century woman of modest gifts among the true seers.

Thomas Hager writes that in the early years of their marriage the couple did not discuss politics with each other, and as proof he observes that Linus reflexively voted twice for Herbert Hoover as president. It is possible that they did discuss politics but that they went their separate ways on these matters. Linus's obsession with his work cut him off from wife and four children, for he would do science and nothing but science all day and every day. "Practically the only time his children talked to him," Hager writes, "was on their drives to and from school, when he would quiz them on their studies."

Hager suggests that Ava Helen came to resent the tedium of housewifery, and "the sense of living in Linus's shadow." Thus her political passion was colored by personal dissatisfaction when she launched a full-out domestic campaign to make this befuddled genius get his mind right. Linus Pauling would always credit Ava Helen with saving him from the moral blindness that afflicted him in his youth: the outmoded Republican confidence that each person is responsible for his own success or failure, and that in a just democratic society the equality of opportunity will necessarily yield a striking inequality of outcome, because there is an undeniable sense in which all men are not created equal.

Ava Helen, reared in a home where socialism shaped the frequent discussion of justice and injustice, taught her husband that this confidence of his only proved his susceptibility to a confidence game, and she brought Linus around to appreciate the inherent wrong of his belief in the ideal of the self-made man, an ideal that may once have fulfilled the frontiersman's need for a totemic source of strength but that now only served to rationalize the worst excesses of selfishness, avarice, indifference to the plight of the poor, and outright capitalist banditry. Linus was made to see that in his rush to make his way out of comparative poverty, he had ignored the multitudes whom he left behind. Pauling remembered in a 1977 interview for the television program *Nova* that as the Depression deepened and the New Deal seemed to some the only way out, "I began listening to what she was saying about the difference between the rich and the poor, the capitalists and the workers. The Democratic Party seemed pretty clearly to correspond somewhat more closely to what I thought was right than the Republican Party."

Relentless table talk and pillow talk gradually steered Linus toward the light; so cocksure in his scientific work, he proved surprisingly malleable in Ava Helen's politicized handling. As Hager writes, "With Ava Helen's urging, Pauling switched parties, and more. Once he began to think about it, he began to see things as she saw them. The deepening economic crisis and the social unrest it engendered seemed to offer proof of the bankruptcy of capitalism." He had been a perfect innocent, the helpless dupe of his upbringing; now he wised up fast, and for good. In 1934, Linus voted for the Democratic candidate for governor of California, the socialist Upton Sinclair, the most celebrated of the literary muckrakers, who had afflicted his countrymen with exemplary moral and physical nausea nearly three decades earlier, as his bestselling novel *The Jungle* exposed the loathsomeness of the meat-packing industry and the need for an American reconstitution on socialist principles. Linus was his own man in the lab and in the seminar room. But when it came to politics, he would be his wife's creature from here on in, though he would often suggest that he was guided by disinterested reason, nature's most precious gift to the scientist, and the scientist's most precious gift to his floundering human comrades.

Man of Peace, Days of War

Of course, Pauling was not alone among scientists in leaning so far to the left. The English crystallographer J. D. Bernal, an unabashed Marxist and world-government man, penetrated Pauling's as-yet uncommitted consciousness with a resounding assertion of the duty of all right-minded scientists, in *The Social Function of Science*, which Pauling read in 1939. Bernal excoriated the scientific community of the time as subservient to the industrial and militarist demands of an oppressive and even monstrous economic order; only by bending their work to the betterment of the toiling masses could scientists fulfill their truly progressive function in society. Pauling had never brought politics into the classroom before, or for that matter adopted any public political role, but now he brought up Bernal's book in his seminar classes at Caltech, and he led the charge toward the universal brotherhood of free and equal human beings, which in order to stand a chance of success really required the direction of extraordinary intellects.

There was a redeeming virtue to Pauling's infatuation with socialist ideas: he became an anti-fascist firebrand, and a more thoughtful one than many on the left, refusing to join the American Association of Scientific Workers, a brainchild of Bernal's, which cleaved to its ever-so-principled pacifism as Hitler was proceeding to take what he wanted of Europe. That Stalin happily joined Hitler in this imperial rapine did complicate the true believers' reverence for the workers' paradise, but many men of good will remained sufficiently reverent to prefer American neutrality to war against the Socialist Motherland; though of course the same peace-lovers who demurred at violence from 1939 through the spring of 1941 would clamor for an Eastern Front after Hitler turned on Stalin in June 1941.

Measured against this company of moral dwarves Pauling looked almost like a full-grown man.

Ava Helen nourished him with the most popular new offering from the shelves of the political health food store: the American journalist Clarence Streit's 1939 book *Union Now*, which called for a democratic conglomerate of the North Atlantic states and beyond to meet head-on the challenge of the totalitarians. The inflamed readership took to action of a sort, and, as Hager reports, sixty Union Now chapters with three thousand members appeared throughout the land. Ava Helen lent a strong hand in the Pasadena office, and she pressed Linus to lend his eloquence to the cause. Responsive as ever to his wife's political prodding, he took to lecturing all over town, on the need to eradicate Nazism and all other dictatorship, and to erect a democratic world government that would ensure peace and prosperity for all men in perpetuity.

Perpetual peace is the hallmark fantasy of the democratic era, common to demagogue politicians, beauty-pageant contestants, and even the occasional philosopher of genius, Immanuel Kant the most notable of the latter. Cranking up the voltage as he approaches the peroration of his *To Perpetual Peace* (1795), Kant attempts to convince his audience that if men can conceive the just world order, they can achieve it:

> Now we have seen above that a federative state of nations whose only purpose is to prevent war is the only state of *right* compatible with their *freedom*. Thus, it is possible to make politics commensurable with morality only in a federative union…and the foundation of right underlying all political prudence is the establishment of this union to the greatest possible extent, for without this as an end all the sophistry of political prudence is contrary to wisdom, hence mere veiled wrong.

Philosophy must prepare the way for this political perfection, by publicly unveiling the sinister and endlessly destructive nature of politics as men have traditionally practiced it, and by educating the rulers and populace alike of the potential for unexampled earthly happiness. Although there is no evidence that Pauling, who preferred reading detective novels to reading philosophy, knew Kant's essay, he tacitly builds on its foundation, and adds the endorsement of an authority more potent in his day than philosophy ever was. As Hager writes of a typical Pauling speech from wartime, "The idea of the 'orderly organism of the world' in which Hitler played the role of a disrupting cancer put Pauling's emerging political sense in line with his view of science. He believed that there existed a world of human affairs, like the world of molecules, that could be understood and made rational. Once again, structure was the key." The optimal political structure was the democratic world state, which recent exasperation with the evils of national and racial chauvinism had made more alluring than ever before—so alluring that human nature was prepared to change itself, with the adoption of a radical pacific cosmopolitanism.

Kant is more than confident that he understands the question rightly, but he nevertheless ends on a note of caution: the salutary transformation of the world can proceed only gradually and will take a very long time. Pauling on the other hand expects mankind to ride the surge of his prophetic energy to the inevitable swift and glorious fulfillment of his vision. And why not? Science speeds ever forward, gaining velocity with each passing moment, while philosophy is prone to dawdle, and slow to excite the compliance of the multitude. It would not do Pauling justice to say that he believed himself to be on the right side of history; he believed that history was decisively on *his* side, and it would arrange itself neatly to conform to the unimpeachably reasonable plans he had for it.

But first there was a war to be fought, in which scientists would play a crucial role. Indeed, as Hager notes, insistent pressure from the president of the National Academy of Sciences, Frank B. Jewett, who happened to be a Caltech alumnus, convinced the United States government to enlist the immense cerebral engine of American science in the war effort, under the Office of Scientific Research and Development. Military brass would brief, say, a roomful of leading chemists on the services' urgent technological needs, and the scientists would take it from there.

One such session got Pauling started on the problem of monitoring the oxygen level in submarines—insufficient oxygen would debilitate the crew, and too much would increase the risk of an explosion. Pauling knew that oxygen, unlike most common gases, was attracted to a magnet, and the more oxygen there was, the greater the attraction; and he knew that Archimedes had measured the density of a liquid by noting how far it would buoy a solid object suspended in it. Pauling reckoned that a body suspended in an air sample would respond to changes in a magnetic field and would register the oxygen level in the air. He sketched a measuring apparatus of exceeding delicacy, presented his plans to a Caltech colleague who constructed a prototype device, and a month later the National Defense Research Committee issued a contract for several hundred Pauling Oxygen Analyzers. Eventually manufactured by Beckman Instruments, a firm founded by a sometime Caltech chemistry professor, the perfected devices would also be used to enhance aviation medicine, improve industrial safety, and maintain healthy oxygen levels in incubators for premature babies.

Pauling also did breakthrough work in developing a superior rocket propellant, which mitigated the chronic problem with weaponry that wandered far off target or exploded in mid-air. This new and improved powder stabilizer of his was dubbed "Linusite," though not by him. He collaborated on an armor-piercing shell; he worked on producing synthetic materials for optical devices of surpassing refinement; he was the indispensable point man in making artificial blood plasma, although demand for the product would be obviated by the overwhelming success of a national blood drive; with his left hand he figured out a code that he was sure would stump the most cunning Axis cryptographers, though the War Department never did get back to him on that.

J. Robert Oppenheimer offered Pauling the directorship of the chemistry division on the Manhattan Project, but he turned down the job. Anthony Serafini, in *Linus Pauling: A Man and His Science* (1989), considers it likely that Pauling's decision was guided by a tremulous premonition of the unprecedented peril the project's success would loose upon the human race. Hager, on the other hand, accepts Pauling's statement that no such moral misgiving prompted his refusal, and he also mentions Pauling's claim that he simply wanted to get on with his own work. Hager is inclined to suspect, however, that Pauling balked at "playing underling to a bunch of physicists," and that moreover, and perhaps more important, he had felt decidedly cool toward Oppenheimer, his erstwhile friend, who fifteen years earlier had invited Mrs. Pauling on a Mexican adventure for two. Sometimes the most high-minded men, especially when they happen to be men in high places, operate on the down-low, just as lesser beings are known to do; and history proceeds accordingly, though historians can be slow to catch on to motives they would rather not know about.

Fellow Traveler

All of Pauling's biographers agree with Pauling himself that the atomic attacks on Hiroshima and Nagasaki changed the course of the scientist's life, even though he didn't realize it right away. As usual, Hager's is the most vivid account of Pauling's gradual emergence as the clarion voice of scientific rationality protesting *fortissimo* that nuclear weapons necessarily made old-fashioned political realism unreal, impossible, insane. A talk Pauling gave to the Hollywood Rotary Club, shortly after the nuclear attacks, about the basic mechanics of the atomic bomb, made his reputation as a local expert intelligible to laymen on this subject so fascinating to everybody, and soon Pauling was a regular on the after-dinner-nuclear-megadeath circuit. Ava Helen egged him on, remarking after one lecture that when he spoke of atomic weaponry he lacked the potent charge he had when he spoke of chemical bonds. Pauling determined to make himself as adept, eloquent, and incontrovertible in his new field as he was in the old. He effectively mastered a new career. Here was an entirely novel subject to think about, to talk about, and it was more urgent and more frightful than any other human matter ever: get this wrong, and Creation is undone. Hager quotes from a letter Pauling wrote to a friend just weeks after Hiroshima: "The problem presented to the world by the destructive power of atomic energy overshadows, of course, any other problem." The imminence of global cataclysm would haunt Pauling at least for the next four decades, and he positioned himself for a commanding role among those opposed to the end of the world.

Scientists tended to presume that they understood the danger best, and were therefore best equipped to conduct wayward humanity to safety. Children of the Enlightenment, congenitally infected with irrational confidence in the power of reason as they understood it, these scientists were taking it upon themselves to disarm atomic energy of its potential for evil and to reassert the unbounded benevolence of scientific knowledge wisely applied. In Hager's words, "They were, of course, hopelessly out of touch with the political realities of the day.... Pauling again was typical."

During the war Pauling had been a wheel in the National Council of American-Soviet Friendship, foreseeing the golden day when the two nations would join in the scientific and humanitarian enterprise free of malice or blighted patriotism, and would carry "the most inspired teachings of each country to the other," as he put it in a 1943 letter. Pauling did understand that Soviet reality had its unpalatable aspects, but then he never had to live in terror of the knock on his door in the night. Thus he was supremely certain that reasonable people could see past these difficulties and work out a harmonious settlement on the essentials.

There are always those, of course, who see things differently. Boris Pasternak was perhaps the greatest Russian poet of the twentieth century; author of the 1958 novel *Doctor Zhivago*, which was banned in the Soviet Union during his lifetime and indeed until the days of *glasnost*, he was forced by the Kremlin to refuse the Nobel Prize. In a 1958 letter, Pasternak observed that "many forgotten periods of history were once thought to be the end of the world, like our present nuclear situation." Alexander Solzhenitsyn, in *The Gulag Archipelago* (1973), tells of political prisoners in a Siberian forced labor camp—a death camp in slow motion—who learned of the American atomic bomb and who taunted the prison guards with the sweet prospect of nuclear annihilation on their very own corner of hell, in just payment for the irredeemable foulness of the Marxist-Leninist-Stalinist world. For the *zeks*, who were being worked and starved and frozen to death with methodical savagery, and who were the preeminent Soviet realists, incineration by American nukes would be a privilege and a pleasure. Even Bertrand Russell, who had served time in prison for his public resistance to the First World War, thought Stalin as bad as Hitler, and in September 1945 shouted for immediate war on the Soviet Union, to take full advantage of America's exclusive possession, which would last only for the moment, of nuclear weapons. In the article "What America Could Do with the Atomic Bomb," Russell declared his preference for "all the chaos and destruction of a war conducted by means of the atomic bomb to the universal domination of a government having the evil characteristics of the Nazis." To assert the moral equivalence of Hitler's Germany and Stalin's Soviet Union, so obvious to some but so contrary to prevailing opinion, took more nerve than it did perspicacity. (True enough, once the Soviets got the bomb, Russell became an advocate of nuclear disarmament and a shrill pacifist voice; in time he would even develop an unseemly and inexplicable infatuation with the Communist dictators of the Third World, Castro chief among them, and an unhinged loathing of the United States.)

The Cold Warriors were willing to live, and to compel their fellow human beings to live, with the relentless awareness that prudence was a hair's breadth from irreparable folly. The French intellectual Raymond Aron, in *The Great Debate: Theories of Nuclear Strategy* (1963), put the matter of utmost gravity with chilling succinctness:

> It is almost impossible to imagine what a war fought with all available weapons would be like without coming to the conclusion that only a madman could possibly unleash it. Therefore it has sometimes been considered preferable to act the madman in order to be taken seriously rather than pretend wisdom in a madman's game—a depressing thought, even if it does contain a grain of truth, and deadly in its implications for mankind as a whole. The Big Two have succeeded in minimizing the dangers of the thermonuclear age precisely because they have never abused this logic of insanity.

Aron wrote books titled *On War* and *The Century of Total War*, with clouds of smoke from a burning city filling the paperback cover of the former. Linus Pauling declared himself the antidote to such snake-bitten craziness, and proclaimed *No More War!* (1958), a classic in Peace Studies featuring a cover photo of the author, benign, self-assured, sage, serene, with a ball-and-stick molecular model in front of him and a blackboard covered with chemist's cuneiform behind him, establishing him as the epitome of reason, which translated perfectly from the study of scientific arcana few understand into common sense about the preservation of mankind that everyone can appreciate.

"It is the development of great nuclear weapons that requires that war be given up, for all time." Thus Pauling writes in the preface, and he proceeds to argue that the most terrible fear mankind has ever faced can and must be replaced by our perfect happiness. He details the geometric increase in kill-power over less than a decade from the devastating A-bomb to the catastrophic H-bomb to the cataclysmic superbomb to the apocalyptic cobalt bomb, which has never been tested because its explosion would likely end all life on earth. He builds his case for an end to nuclear weapons testing, explaining the genetic insult visited upon dozens of human generations by radioactive fallout. He claims the support of the world's leading scientists for the necessary end to nuclear weapons testing and stockpiling and declares it high time to institute world-wide "*research for peace*."

In December 1947, Pauling vowed that in every talk he gave he would mention the need for world peace. He did quite well by his promise. Pauling wrote scores of op-ed jeremiads; delivered hundreds of vehement addresses; professed repeatedly his friendship for the people of the Soviet Union; considered himself honored for being named a member of the Soviet Academy of Sciences; took a line on many issues that could easily be considered pro-Soviet and anti-American; testified before a Senate subcommittee that this friendship and pride and exercise of free speech did not vitiate his all-American wholesomeness; fought a running and not always successful battle against State Department officialdom disinclined to let him travel abroad; filed one lawsuit after another against journalists who impugned his patriotism and even accused him of Communist sympathies (most notably William F. Buckley, Jr., who was faced with the loss of his *National Review* but who cleaned Pauling's clock in court); authored countless petitions and signed on to many more; became a familiar face at colloquies of the world's authorities on peace and justice, his heroically weathered yet innocently beaming visage becoming well known to the

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great public. In short, he made the sort of resounding noise in favor of all that is right and against all that is wrong that men of good will often take for profundity and courage. So it was that after President Kennedy and Premier Khrushchev terrified each other and the rest of the world over the matter of nuclear missiles in Cuba, and the two leaders subsequently signed a nuclear test ban treaty, Pauling received his second Nobel Prize, this one for Peace, becoming the first person ever to receive two unshared prizes. He would say that the Peace Prize meant more to him than the one in Chemistry, because the scientific honor came for his doing what he selfishly loved to do, while the humanitarian honor recognized work he did out of his moral conviction. Some near to him would have preferred he stick to chemistry: Pauling departed Caltech in a snit when the university president publicly appeared to question the soundness of Norwegian political thinking in giving him the Peace Prize.

So who understood the crucial matter of the time rightly? Who knew best what had to be done? "The time has now come for morality to take its proper place in the conduct of world affairs; the time has now come for the nations of the world to submit to the just regulation of their conduct by international law." There is the summation of Pauling's political wisdom, stated with the eloquent concision that comes of supreme self-assurance, breathing common sense and calm to cool the overheated passions that threaten the world with extinction, quite sure that there is only one right way to see the crisis and thus only one possible way out of it: the surrender of national sovereignty to universal rationality, putting an end to nuclear tests as the first step in our "unique epoch in the history of civilization when war will cease to be the means of settling great world problems." This is the mind of a man accustomed to being right, and to being admired for being right. Yet in this case he proceeded with headlong utopian logic to get it exactly wrong. For genuine prudence belongs to those who simultaneously plan for war and for peace, and who have sustained liberty against tyranny precisely by being prepared to fight and by fighting when necessary—for history has shown that law and rationality are no defense against the weapons of tyranny.

From Megadeath to Megadoses

If there is a modern project as consummately hopeful as the clamor for universal peace, it is the promotion of good health and long life. The saviors of mankind gravitate instinctively to these two causes, and Linus Pauling, having done his part to end war forever and prevent the extinction of the human race, turned his attention naturally enough to the systematic postponement, if not the outright abolition, of individual human death.

In 1966, when he was sixty-five years old, he gave a speech in which he mentioned in passing that he would like to hold on to life for another twenty some years, so that he could see the scientific advances to come. A biochemist in the audience, Irwin Stone, wrote to inform Pauling that he need only take vitamin C by the fistful every day in order to last another *fifty* years. Ted Goertzel and Ben Goertzel observe that Pauling had nothing else consuming to think about at the time, and that here was a matter of considerable scientific interest that also promised to be of immense social importance. To curtail human suffering so wondrously—eradicating cancer and heart disease, alleviating schizophrenia, not to mention eliminating the common cold—and to extend the normal lifespan by decades would be the perfect fulfillment of Pauling's career, in which studiousness originally for its own sake had come to serve the human good as most modern people understood it. He had begun by explaining how molecules held together, gone on to understand the molecular foundations of life, been the first to identify a molecular disease (in sickle-cell anemia), deployed the arsenal of his scientific knowledge and moral wisdom in mortal combat against the forces of darkness, and now would deliver mankind from much pain, sorrow, and premature death. The benefit would be incalculable, and Pauling would prove himself invaluable: *the* necessary man of the twentieth century, who would be remembered centuries hence, when pretenders to that honor such as Einstein and Churchill were forgotten.

As Pauling pursued his new line of inquiry, his confidence in his rightness swelled ever faster. He was used to seeing farther and more clearly than anyone else, and there was no reason why his panoptic virtuosity would lead him astray here. The titles of his bestselling books demonstrate the continually expanding scope of his promise to transform medicine and make human life more agreeable than it had ever been since the expulsion from the Garden: *Vitamin C and the Common Cold* (1970); *Vitamin C, the Common Cold, and the Flu* (1976); *Cancer and Vitamin C* (1979, coauthored with Ewan Cameron); and *How to Live Longer and Feel Better* (1986). In the latter, Pauling staked his claim to the breakthrough in nutrition that will transfigure the dodgy art of medicine into unimpeachable scientific practice at long last. "I have coined the term *orthomolecular medicine* for the preservation of good health and the treatment of disease by varying the concentrations in the human body of substances that are normally present in the body and are required for health." The judicious use of vitamin supplements will supplant the current reliance on drugs, which do not occur naturally in the body and tend to have nasty side effects. Pauling credited a doctor sympathetic to his cause with the witty neologism *toximolecular medicine*, which nails the perversion of the healing art by the predominance of poisons in the standard pharmacopoeia.

Pauling explained that "the discovery of vitamins during the first third of the twentieth century and the recognition that they are essential elements of a healthy diet was one of the most important contributions to health ever made." Where conventional medicine had gone wrong was in emphasizing the treatment of vitamin deficiency while remaining ignorant of the optimum levels of vitamin consumption, which contributed to a heroic glow of physical and mental well-being far superior to the condition of persons considered healthy by common standards. To restrict one's intake of vitamin C to the government-sanctioned Recommended Daily Allowance of 60 milligrams ensured that what the experts called ordinary good health was in fact "ordinary poor health." Pauling, ever ambitious, helped himself to 3,000 mg per day, and later in life, to as much as 50,000 mg per day.

The Hungarian physiologist Albert Szent-Györgyi, who in the early 1930s first isolated a substance that he recognized to be vitamin C, declared that vitamins correctly used could produce "fantastic results," in Pauling's phrase. Szent-Györgyi responded to a Pauling query in 1970 by blaming doctors at large for having "misled the public" about vitamin C from the very start: "If you don't take ascorbic acid with your food you get scurvy, so the medical profession said that if you don't get scurvy you are all right. I think that this is a very grave error. Scurvy is not the first sign of the deficiency but a premortal syndrome, and for full health you need much more, very much more." Pauling intended to stick the knife into "the sickness industry," and to realize the untapped human potential for Edenic vim, vigor, and enjoyment of life.

He founded his outsized claims for orthomolecular medicine on the physical-chemical-biological science he so largely developed. No one else was so well qualified as he to spearhead the medical avant-garde, for his matchless store of information fed his powers of sensible imagination. "We know and are learning to know better just what role each vitamin molecule plays in the chemistry of the body," he wrote. "Thus, by the classic interaction of clinic and laboratory, molecular biology explains what the clinic finds, and the clinic confirms the optimum intakes commended by molecular biology."

Pauling thought he was building his theory about vitamin C on scientific evidence, including a few studies that he thought supported his claims. But the medical professionals and the scientific journals and the U.S. Food and Drug Administration soon reacted, denouncing Pauling and revealing, correctly, that his claims and conjectures were too big for the puny scientific scaffolding holding them up. Yet the public believed him, and Pauling's confidence, if anything, only grew. Anecdotal evidence of the effect of vitamin C to prolong cancer patients' lives launched him into further speculations and publications. He increasingly relied only on the research and reports of others instead of putting his own sharp mind to work.

Thus Pauling became a leading prophet of the wellness movement, instructing the citizenry in the routine of the sainted healthy lifestyle, notably sound diet, regular exercise, hydration, rejection of tobacco, moderate alcohol use, close family ties and friendships. And who is to say no to any of that? Odds are that one's health provider's website preaches the benefits of virtuous adherence to such a regimen, and the dire consequences of failing to get with the program. And there is a lot to be said for the smokeless, aerobic, nutrient-rich, well-watered life, however noisome it might be to see the fitness devotee extolled as the modern rival to the Aristotelian great-souled man.

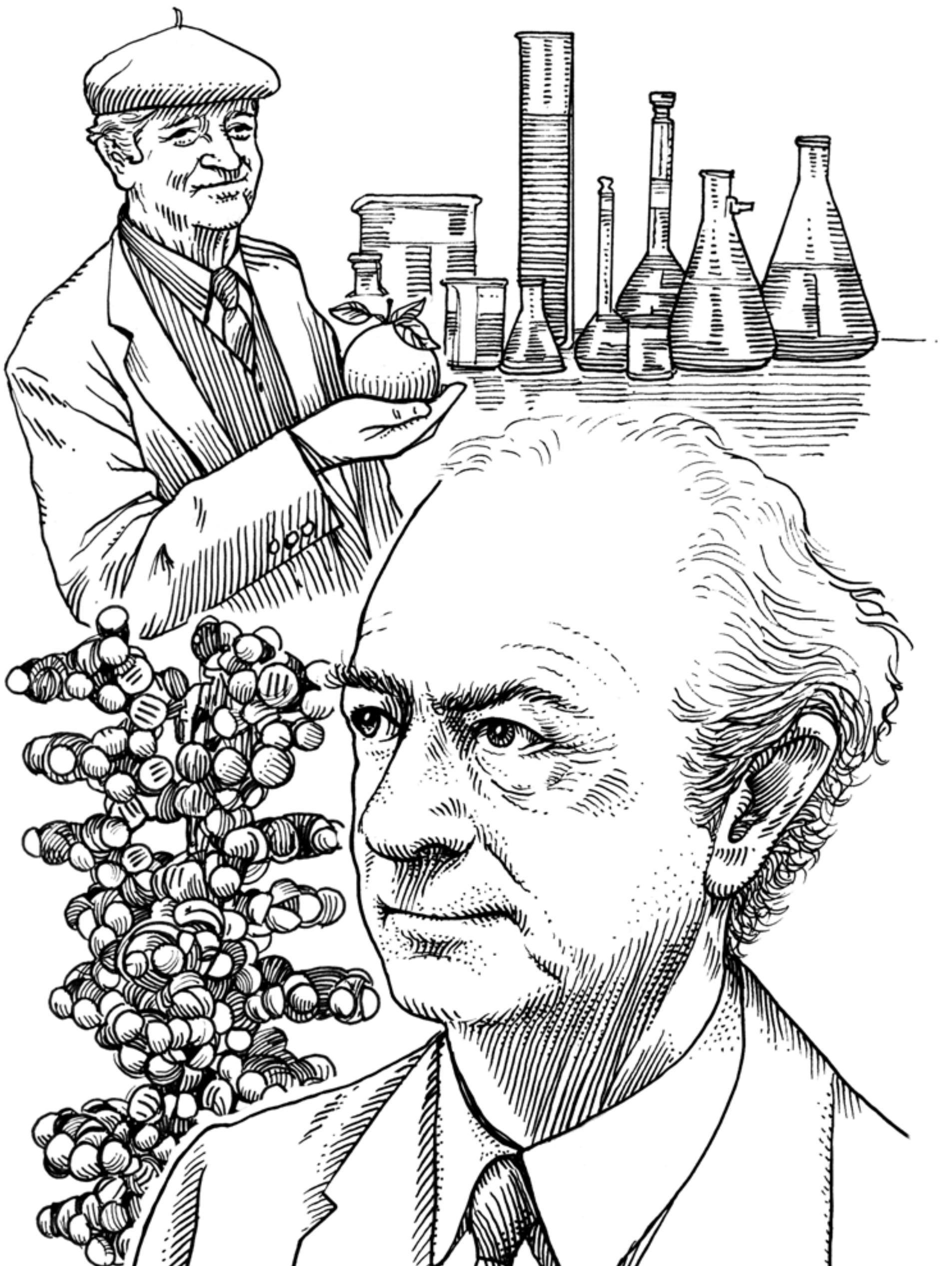
But as the wellness industry is fast gaining ground on the sickness industry, its enticements do include more than a few high-speed screwballs from the mountebank repertoire, from aromatherapy to the empowering energy of crystals, generally under the name of alternative medicine. Nice smells and colorful stones and all the rest are pretty well harmless when employed as instruments of wellness. But alternative medicine is most pernicious as the staple of a sickness industry newly conceived, which promises to cure the hardest cases, as acupuncture, chiropractic manipulation, juice cleanses, and apricot-pit extract purchased in Ciudad Juárez become the treatments of choice when one's life is on the line, thereby ensuring devastation and death where a cure by legitimate medicine was actually possible. Wellness does inevitably fail, and when a chance of recovery from life-threatening illness remains, it is the old-fashioned sickness industry, with radiation, chemotherapy, and surgery, that offers the real hope.

Pauling himself would surely have denounced much of today's alternative medicine as unscientific quackery, but he inspired and contributed to it, trading on his scientific authority to promote what at times amounts to medical malpractice—and prompted by the saddest deception there is, the self-deception of a gifted man who believes he alone understands.

When Ava Helen Pauling was diagnosed with stomach cancer, she underwent surgery—but instead of having the chemotherapy her doctors recommended, she chose daily megadoses of vitamin C. She died in 1981 at the age of 77. Linus Pauling lived another thirteen years, dying of prostate cancer in 1994. He was 93.

When a Great Mind Stumbles

If this were a Thomas Mann story in which the hero attains greatness despite the stifling hostility of his miserable bourgeois family, one would note the signposts that Destiny carefully placed along the hero's processional route toward consummate literary excellence and universal fame, but also most likely to an unexpected dire conclusion. Pauling was a very different sort of creature, and it would not have occurred to him to understand his life that way; science in its very essence abhors poets' loose talk of fated vocation, of supernatural election into the exalted company of those born to understand and to create. Just the same, Pauling's life story is rich in fateful encounters, momentous decisions, unexpected turns, exploding crises, all evidently leading to one thrilling discovery after



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another that in sum would define the course of modern chemistry, physics, and biology—nothing less than science as we know it.

Of course, if one is disinclined to believe in unseen Powers that take a particular interest in some few men and women and direct them to bend the course of history this way or that, there are other interpretations more congenial to unadulterated straightforward reason. What appears as Fate to the poets looks more like chance to the hard-headed, and the succession of chance events does not amount to necessity, but rather proves the contingency of human thought and action.

Any individual life could have turned out far differently than it did, and if the person in question is a scientist of genius, in his decision to take one path rather than another, to chase down the answer to some question he focused on because a professor or colleague happened to bring certain curious facts to his attention, when he might have found himself in an altogether different classroom or laboratory, for that matter when he might have chosen to study law or medicine or to work in a machine shop, his life story affects the history of science and thus the history of mankind. The gross presumption current among many educated people unfamiliar with the history of science conceives scientific discovery as an unrelenting advance upon the whole truth about the natural world, which will inevitably yield its innermost secrets: we know this and we know that, and knowing this and that leads naturally to knowing more here and there and then some, so that our insights proceed in their appointed order, the tumblers click as they must, and the safe will open and its contents be disgorged for all to see. But this is not the way things work. The history of science depends on individual biography to a significant degree—sometimes to a decisive degree. And great minds in motion often stumble upon the truth or into falsehood. Such a prominent role for sheer luck upends the commonplace understanding of scientific progress.

It was not only in the particular discoveries he made—a good number of which were stunning—but also, and perhaps even more so, in the way he pursued his vocation that Pauling made his lasting scientific mark. Pauling's intellectual heroism lay in the superabundant mental energy he brought to most any question that crossed his mind. So much of his life's work is exhilarating to read about precisely because he lived in a state of unflagging exhilaration.

The ease with which he leapt from one discipline to another, however, stoked a fatal indiscipline. Convinced that he understood the most urgent political questions facing mankind despite the hopelessly fogged-in political actors and intellectuals who thought him a flatulent ninny, certain that he pointed the one true way to ultimate human thriving despite the caviling medical professionals who in their self-conceit and self-interest pronounced him a dangerous charlatan, he proved in the end, both in politics and orthomolecular medicine, a flatulent ninny and a dangerous charlatan.

It is hard to think of another man of science so joyous in his vocation, so alive in the essential parts of his intellectual being. And it is hard to think of a sadder end for so illustrious a mind than this self-willed descent into arrogant folly, quite beyond his mental scope, colossal though that was. The man who thought of everything became the swell-headed crank who can't be told anything. Linus Pauling paid for his extraordinary gifts with his failure to appreciate where they rightfully ended. One cannot but think what a marvelous legacy would have been his if he had just known when to quit.