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STERLING BROWN HENDRICKS

*1902—1981*

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*A Biographical Memoir by*

WARREN L. BUTLER AND CECIL H. WADLEIGH

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*Biographical Memoir*

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*Sterling B. Hendricks*

# STERLING BROWN HENDRICKS

*April 13, 1902–January 4, 1981*

BY WARREN L. BUTLER AND CECIL H. WADLEIGH

*Freedom to inquire into the nature of things is a rewarding privilege granted to a few by a permissive society.*

Sterling Hendricks  
*The Passing Scene*, 1970

STERLING BROWN HENDRICKS was born in Elysian Fields, Texas, a small village in the eastern part of the state. The family had deep roots in the Old South. When Texas seceded from the Union in 1861, the area around Elysian Fields sent a company of men, known as the S. B. Hendricks Company, to the Confederate Army under the command of Colonel Sterling Brown Hendricks, Sterling's grandfather. The colonel, a native of Alabama, grew up and studied law in Mississippi and moved to Elysian Fields in 1843, where he became a merchant and a farmer. He was also a scholarly man with a large library of books on law, religion, and the classics.

Sterling's father, Dr. James Gilchrist Hendricks, was born in Elysian Fields in 1854. He received medical degrees from Louisiana and Tulane universities in New Orleans and, after interning at Bellevue Hospital in New York City, returned home to practice medicine. Sterling's mother, Martha Daisy (Gamblin) Hendricks, was born in Caddo Parrish, Louisiana, in 1873. She graduated from Mansfield Female College in Louisiana as valedictorian of her class. After graduation, she went to Elysian Fields to teach school and met Dr. James Hen-

dricks, who was then a widower. They were married in 1893 and had five children; Sterling was the fourth.

Sterling received much of his early schooling from his mother. There was no high school in Elysian Fields (only a one-room school house), so Sterling lived with an aunt in Shreveport, Louisiana, during his high school years. Following his graduation, the family moved to Fayetteville, Arkansas, so that several of the children could attend the university there. Sterling graduated from the University of Arkansas in 1922 with a bachelor's degree in chemical engineering. He studied geology and chemistry at the graduate level at the University of Iowa in 1923 and received a master of science in chemistry from Kansas State University in 1924. Then, in the fall of 1924, he began his doctoral studies at the California Institute of Technology.

On entering Cal Tech, A. A. Noyes, the director of the Gates Chemical Laboratory, suggested to Sterling that he work on X-ray crystallography in the laboratory of Roscoe C. Dickinson. Dickinson, who four years earlier had received the first Ph.D. degree given by Cal Tech, was going to Europe that year, so Sterling worked with Linus Pauling, who had arrived in Dickinson's laboratory two years earlier to learn the techniques of X-ray crystallography. Thus began a close friendship that lasted until Sterling's death. Sterling received his Ph.D. degree in 1926, with a major in chemistry and with minors in physics and mathematical physics.

Sterling began his Ph.D. research with a reinvestigation of the structure of the minerals corundum,  $\text{Al}_2\text{O}_3$ , and hematite,  $\text{Fe}_2\text{O}_3$ , which had been studied earlier by W. H. and W. L. Bragg. He confirmed that the positions previously assigned to the aluminum and iron atoms were correct, but the positions for the oxygen atoms were not. The refined structure provided a clearer understanding of the interatomic forces in these crystals. He also determined the structure of

sodium and potassium azide, showing that the three nitrogens were in a linear array rather than in a cyclic structure—as had been proposed by some chemists. His Ph.D. thesis also included the determination of the crystal structures of several cupric chloride dihydrates. He also worked jointly with Maurier L. Huggins, a postdoctoral fellow in the laboratory, on the structure of pentaerythritol,  $C(CH_2OH)_4$ . Sterling pointed out that the pyramidal structure that had previously been proposed might be incorrect, and that another space group permitted a tetrahedral arrangement of the bonds around the central carbon atom. This latter structure was confirmed a decade later.

He continued structure determinations of simple organic compounds during two postdoctoral years—1926–27, at the Geophysical Laboratory of the Carnegie Institution of Washington, and 1927–28, at the Rockefeller Institute of Medical Research—with work that made important contributions to the chemistry of carbon compounds. In 1928 he joined the Fixed Nitrogen Laboratory of the U.S. Department of Agriculture. He was recruited by F. G. Cottrell, who hoped to benefit mankind by solving the problems of nitrogen fixation. In later years Sterling would often speak of Cottrell. Cottrell, as the inventor of the electrostatic precipitator, donated the returns from his patents to support research through grants from the Research Corporation. It was from Cottrell that Sterling gained an appreciation for practical applications of scientific research. For Sterling, the highest goal of science was to achieve a solution to an important practical problem.

In the years that followed, Sterling made monumental contributions to mineralogy and the study of soils. His early Ph.D. research on corundum and hematite was followed by studies of other minerals, including zircon, apatite, gypsum, kaolinite, anauxite, valentinite, alunite, the jarosites, dickite,

halloysite, hydrated halloysite, talc, pyrophyllite, vermiculite, chlorite, montmorillonite, nacrite, cronstedite, glauconite, celladonite, gibbsite, endellite, and the micas. This work resulted in an extensive understanding of clays as important components of soils and of the structural basis of ion exchange of charged groups—central to understanding soil fertility. He used his expertise in X-ray diffraction and mathematical physics to determine the structure of phosphate fertilizers and also of bone. In terms of human welfare, one could make a strong case that Hendricks' most important research was in collaboration with soil scientists toward determining the structure of soil constituents. In 1930 Hendricks and Fry published the results of their research on soil colloids. This paper is now recognized as the most important elucidation of the nature and properties of soils ever published. A bit of history may be in order.

In 1850 a Scottish chemist by the name of J. T. Way published a paper on the power of soil to absorb manure. He had allowed moderately dilute solutions of neutral salts to seep downward through soil columns. He collected the percolate and found that its chemical composition was usually different from that of the applied solution. For example, when an ammonium chloride solution was applied, the percolate contained little ammonium; the percolate was mostly calcium chloride. Way concluded that there was an interaction between the applied solution and the soil particles. He erroneously concluded that the reaction was irreversible. The distinguished German chemist, Justus von Liebig, looked on Way's report with utter contempt and had no reservations in saying so. For the next three-quarters of a century a vigorous controversy prevailed among soil chemists; some supported Way and others Liebig. These arguments were settled for all time by the publication of the paper by Hendricks and Fry. By using X-ray diffraction procedure, they conclusively

proved the crystalline nature of colloidal clay with the prevalence of negative charges that would absorb and desorb cations. They showed that Way was on the right road.

With the exponential increase taking place in world population, with the prevalence of famine and malnutrition on this planet, and with the finite limitation on the extent of arable soils available for food production, this research by Hendricks and Fry was of inestimable value. These findings opened the door to an exceedingly important understanding of the chemistry involved in maintaining high potential in soil productivity, and in providing a valid chemical basis for the reclamation of the alkali soils of arid regions.

In 1952 Sterling received the Arthur L. Day Medal awarded by the Geological Society of America for outstanding work in physics and chemistry advancing the geological sciences. The citation stated:

Sterling Hendricks, an able technician and a masterful and imaginative theoretician, has been in the forefront of those who have given us a rational understanding of these most complex and most important minerals. His elucidation of the structure of layered minerals and his demonstrations of the dependence of clay mineral properties upon structural considerations have been outstanding. Not only has he provided specific data on the kaolin minerals and, with Ross, on the complex montmorillonite group, but he has at the same time developed fundamentals of broad application, as for example in his studies of the polymorphism of the micas and of the nature of the water layer, and in the determination of minerals with disordered structure and of minerals with random layer sequences. He has never been content merely to explain the well-behaved growths in the mineral world, but has gone on to decipher for us some of nature's "mistakes."

Linus Pauling considers that Sterling's work on the clay minerals was his most important contribution to knowledge.

The work on soils and fertilizers also led to investigations of hydrogen bonds. Hendricks was among the first to use

infrared spectroscopy for the study of molecular structure. Pimentel and McClellan wrote, some twenty-five years later in their book on the hydrogen bond, that this work provides “. . . the most sensitive, the most characteristic and one of the most informative manifestations of the H-bond. From this has grown the immense volume of work. . . .” Hendricks also became an expert in radiochemistry, and he showed how fertilizers tagged with radioactive phosphorus could be used to follow the uptake of phosphorus by the roots of plants. Of course, not all of his scientific endeavors were successful. Sterling tried to obtain a diffraction pattern from crystals of horse hemoglobin some five years before the first successful X-ray crystallographic studies of a protein were made in Cambridge, England. His attempts failed because the protein denatured as the specimen was dried for mounting. He also attempted to obtain a diffraction pattern of a chromosome before it was known how nucleic acids could be separated in a native state. Thus, in the course of many successes he had some grand failures—but even the failures pointed toward forthcoming spectacular successes in biology.

Sterling's scientific career took an abrupt change in direction in the early 1940s. A brief history of this period and the subsequent developments is appropriate since it was in these new areas of plant physiology and photobiology that his most creative contributions to knowledge lie. In 1920 two scientists in the USDA, H. A. Allard and W. W. Garner, discovered that daylength was a critical factor in determining when during the course of the year a given species of plant would flower—a phenomenon which they called photoperiodism. By the middle 1930s the work on photoperiodism was being continued in the USDA by H. A. Borthwick and M. W. Parker, primarily in studies of the flowering of short-day plants (plants that flowered on a short day—long night regime). In the early 1940s they sought out a fellow USDA employee,



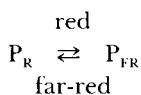
Hendricks, to discuss how they should proceed in their investigation of the effects of light in photoperiodism. It was then known that brief irradiations with light given during the long nights would inhibit the flowering of short-day plants. They realized that they might be able to determine the action spectrum (that is, the effectiveness of different wavelengths of light) for this inhibitory effect of light on flowering, and they agreed to pool their scientific talents toward this end. World War II intervened, and it was not until 1944 that they began their collaboration.

The key to the early successes of this work lay in the experimental design of the action spectroscopy. A large spectrograph was constructed using two exceptionally large glass prisms, which Hendricks had used previously for his infrared studies of hydrogen bonds, and a large second-hand carbon arc lamp like those used in theatres of the time. Absolute energy calibrations were made across the spectrum using a thermopile that was calibrated against a standard lamp. Of equal importance to the success of the work was the knowledge of how action spectra should be measured. Hendricks understood that it was essential to keep the irradiation periods brief to extract the specific characteristics of the photo-reaction from the great complexity of the biological response, which might be assayed some hours or days later. Borthwick and Parker provided the plants whose flowering response was sensitive to brief periods of irradiation, and Hendricks provided the irradiation fields of large area, high spectral purity, and adequate intensity. Within a year they had an action spectrum for the floral inhibition of a short-day plant, soybean, which showed a pronounced sensitivity to red light.

Action spectra were then measured on a number of different plants and on several different light-sensitive responses, including the floral inhibition of other short-day plants, the flowering of long-day plants where the night-

break irradiation induced flowering, several growth responses in etiolated plants grown from seed in darkness, and the germination of lettuce seed. All of these investigations yielded essentially the same action spectrum, with a peak action in the red near 660 nm. It was concluded that the same pigment was involved in all of these responses.

The experiments on seed germination were to provide key observations for elucidating the unusual photochemical properties of the pigment. It was known from earlier long-term irradiation experiments (by Flint and McAlister) that red light promoted the germination of lettuce seed. The USDA group expected to find their typical red action spectrum for this response. Flint and McAlister had also reported, however, that light in the near infrared region, just beyond the limits of vision, inhibited the germination—but the significance of the inhibitory effect of such wavelengths of light was generally unappreciated. The USDA group rediscovered the inhibitory effect of these far-red wavelengths of light. They demonstrated that seeds potentiated to maximal germination by a brief irradiation with red light could be inhibited to minimal germination by a subsequent brief irradiation with far-red light, and that these promotive and inhibitory effects were repeatedly reversible. The action spectrum for the photoinhibition of germination showed a maximum at 730 nm. Hendricks deduced from these experiments that the germination of lettuce seed was controlled by a pigment that existed in two interconvertible forms: a red absorbing form,  $P_R$ , with an absorption maximum at 660 nm, and a far-red absorbing form,  $P_{FR}$ , with an absorption maximum at 730 nm. He concluded that red and far-red light caused transformations between the two forms:



After the unusual property of photoreversibility had been found in the germination response of lettuce seed, the other red-sensitive photoresponses were reexamined. They were found to show the same type of photoreversible antagonism between red and far-red light. The unique and unusual pigment system appeared to be ubiquitous in higher plants and to control a number of physiological responses.

Hendricks was primarily responsible for the incisive insights that penetrated to the molecular level of the photocontrol process. A given degree of a physiological display would be used as an endpoint in a titration of responses versus incident energy. Whereas most plant physiologists of the time became lost in the great complexity of the biological system, Hendricks designed experiments in such a way that the complexities of the dark metabolism canceled out, leaving the pristine properties of the photoreaction to be revealed. The elegance of the approach culminated in a remarkable study. The physiological responses of seed germination and internode elongation of etiolated bean plants were titrated from both extremes of the reversible photoreaction, using red and far-red light. After making allowances for the light-scattering properties of the biological tissue and the quantum efficiencies of the photoreactions, Hendricks calculated—from the absolute energies required to achieve given degrees of response and the first-order nature of the photoreactions—that the molar extinction coefficients of the two forms were between  $10^4$  and  $10^5$  liters mole<sup>-1</sup> cm<sup>-1</sup>. He concluded—on the basis of these high values for molar extinction coefficients and the absence of any visible color in albino mutants of barley, whose growth responses were fully sensitive to red and far-red light—that the pigment system was functional at very low intracellular concentrations. The insight and clarity of vision that allowed Hendricks to extract a molar extinction coefficient from a complex physiological display were char-

acteristic of his approach to science. Unfortunately, the paper reporting these findings was largely ignored. At the time, few workers in the field made the effort to follow the logic of the analysis.

Hendricks had deduced the essential molecular properties of this remarkable pigment system from the physiological studies by the early 1950s. The absorption spectra of the two forms and the reversible nature of the photoreaction were known from the action spectroscopy. It was proposed from the absorption spectrum that the chromophore of  $P_R$  was an open-chain tetrapyrrole, similar to that of allophycocyanin. It was even proposed, on the basis of the low intracellular concentrations, that the pigment was an enzyme, and therefore a protein, and that  $P_{FR}$  was the active form of the enzyme. In addition to the photochemical properties, the physiological studies indicated that there was a slow dark transformation of  $P_{FR}$  to  $P_R$ . This dark transformation of  $P_{FR}$  back to  $P_R$  was proposed to be the basis of the timing mechanism that enabled photoperiodic plants to distinguish long nights from short nights. Nevertheless, most plant physiologists of the time did not believe that their subject matter was capable of revealing such molecular detail and, in the absence of direct proof, they were inclined to regard the pigment as a "pigment of the imagination."

Sterling's group had the good fortune to join another group headed by Karl H. Norris, an agricultural engineer who had developed several spectrophotometers that could accommodate dense, light-scattering materials. From time to time Hendricks or H. W. Siegelman, a plant biochemist who was then associated with Borthwick and Hendricks, would examine these samples in the spectrophotometer for photo-reversible absorbance changes in the red and far-red regions of the spectrum. All of the initial attempts with plant tissues that were known to be sensitive to red and far-red light were

unsuccessful, and concern arose that this approach was hopeless because of the very low intracellular concentration of the pigment. Finally, in the summer of 1959, in spectrophotometric measurements of cotyledons from dark-grown turnip plants that synthesized anthocyanin under control by red and far-red light, the absorbance changes were found. The difference spectrum between the red and far-red irradiated tissue was precisely what the action spectra predicted, and the effects of light were fully reversible. Furthermore, the photoreversible nature of the pigment persisted in cell-free extracts of the plant tissue. The pigment was immediately shown to be a protein by heat denaturation, and Siegelman took on the task of purifying the material. The success of these measurements depended on finding a tissue that had measurable amounts of the pigment. For reasons that are still not understood, dark-grown seedling plants accumulate much higher levels of the pigment than are needed for photocontrol purposes in mature green plants. The pigment was dubbed phytochrome, which Hendricks seemed to resist initially, but he recognized the utility of having a trivial name and soon came to accept it.

All of the essential predictions that Hendricks had made over the years were confirmed once the purified material was in hand. The absorption spectra of  $P_R$  and  $P_{FR}$  were right on the mark. The reversible photochromic nature of the pigment persisted in the purified state, the pigment changing from a blue color in the  $P_R$  form to less colored, slightly more greenish hue in the  $P_{FR}$  form. The estimates of the extinction coefficients proved correct, and chromophore was found to be an open-chain tetrapyrrole, of the type suggested, that isomerizes under the action of light. The chromophore is attached to a protein, and the  $P_{FR}$  form appears to be the active state of the combination. And the dark transformation of  $P_{FR}$  to  $P_R$ , which was postulated to be the basis of the timing

mechanism of photoperiodic plants, was shown to occur *in vivo* by direct spectrophotometric measurements. Surely, if Alfred Nobel had seen fit to include the plant sciences amongst his prizes, Sterling Hendricks would have been a recipient.

Sterling's work on phytochrome and the physiological responses controlled by phytochrome continued to his death. Most of the initial speculations about the mode of action of phytochrome centered about the mechanism of gene activation. In studies of leaf movement, Hendricks and Borthwick made the seminal discovery that control was exerted at the level of membranes. After his formal retirement from the USDA in 1970, he continued studies of seed germination and the nature of dormancy with great vigor in collaboration with R. B. Taylorson. They decided to use seeds as media with which to probe the mechanisms of phytochrome action, as well as the basic nature of dormancy. They began by probing the nature of phytochrome action as affected by temperature change. Evidence began to indicate that cell membrane activity was involved in temperature effects on seed germination. Data revealed leakage of amino acids as a function of temperature. Changes in germination physiology were again found to correlate with observed effects of temperature on changes in fluorescence associated with membrane preparations.

The team of Hendricks and Taylorson pursued studies on the action of anesthetics as seed germination stimulants. Low molecular weight alcohols, aldehydes, and similar structures are active as anesthetics in animals. Anesthesia is associated with effects on cell membranes in animals. Membranes so treated tend to swell, and it was of interest to ascertain the counteractive effect of hydrostatic pressure on anesthetic action. The findings accordingly linked anesthetic action in seeds with membrane phenomena found in animal systems.

The studies led to the suggestion that dormancy control in seeds is a function of cell membranes.

Sterling's science was characterized not only by its depth of penetration but also by its incredibly broad scope. Over the years he lectured to scientific organizations and to university groups on the structure of matter, electron diffraction from gases, the nature of bone, hydrogen bonding in organic compounds, base exchange in soils, photosynthesis, plant nutrition, radioisotopes in agriculture and, of course, many aspects of photomorphogenesis in plants. Something of that breadth and depth was indicated by his election to the National Academy of Sciences. In the early 1950s, when the Botany Section was considering him for nomination, they found that he was also being considered by the geologists and the chemists. He was elected to the Academy in 1952, at a time when there were 480 members. He joined the Botany Section and was active in the affairs of the Academy for the rest of his life.

Sterling's great breadth of science is also indicated in the many honors that came to him over the years. There was the Hillebrand Prize in 1937, awarded by the Chemical Society of Washington for outstanding work using the optical properties of crystals in the analysis of atomic arrangements; the Science Award of the Washington Academy of Science in 1942, for discoveries about the rotation of molecular and ionic groups in crystals; and his election as fellow of the American Society of Agronomy in 1945, in honor of his discovery of the nature of soil clays and the significance of cation exchange. The Day Medal, which he received from the Geological Society of America in 1952, was mentioned earlier. He was the fourth recipient of that award. He also received the Distinguished Service Award from the U.S. Department of Agriculture in 1952 for his contribution of fundamental knowledge to the advancement of science. In 1954 he was

elected president of the Mineralogical Society of America and a trustee of the American Society of Plant Physiologists. In 1958 he was in the first group of five recipients to receive the President's Award for Distinguished Civilian Service from President Eisenhower. Other recipients that year included FBI Director J. Edgar Hoover and Ambassador Charles E. (Chip) Bohlen. Hendricks' citation read: "His discoveries in soil clays, phosphate minerals, radioisotopes, plant physiology and fundamental chemistry made him one of the most distinguished and honored scientists of our time." He was elected president of the American Society of Plant Physiologists in 1959. He received the Rockefeller Public Service Award in 1960 and shared the Hoblitzelle Award in the Agricultural Sciences with H. A. Borthwick in 1962. He and Borthwick also shared the Stephen Hales Award from the American Society of Plant Physiologists in 1962. In 1968 he received the Distinguished Alumnus Award of the California Institute of Technology. He was awarded the National Medal of Science from President Ford in 1976, and in the same year the Finsen Award, which is the highest honor bestowed by the International Society of Photobiology. From 1974 to his death he was a member of the Committee for Research and Exploration of the National Geographic Society, where his great breadth of knowledge was put to good use to evaluate applications for research grants. There he was known as "a man for all seasons." As a member of that committee, he made field trips to Kenya, Tanzania, Jordan, Iran, and Israel. On the day of his death, the flag was flown at half mast over the National Geographic Society Building in Washington, D.C.

Outside of the laboratory, Sterling's main diversion was mountain climbing, and he seems to be regarded as highly among alpinists as he is among scientists. His obituary in the *Washington Post*, which was headlined: "Chemist Was in Group



that Climbed McKinley," referred to him as "a chemist and a mountain climber of note." *Up Rope*, a mountaineering publication, after paying tribute to his accomplishments in science, stated that he was a pioneer in American mountaineering whose "attainments were comparable with or even superior to—if possible—those in science." His love of nature undoubtedly began as a boy in Elysian Fields, which was named for its lovely countryside of rolling hills and pine forests. As a graduate student, he back-packed about 100 miles through the Santa Lucia mountains of California, from Cambria to Monterey. He was also a long-distance swimmer, and at one time he attempted to swim around Catalina Island, but history does not record whether that attempt was successful. He was a member of the Alpine Clubs of the United States and Canada. During the 1930s, Canadian authorities officially recognized that he climbed four previously unscaled peaks in the British Columbian Rockies. In 1942 he was a member of the third party to conquer Mount McKinley in Alaska, North America's highest mountain. These excursions did not always go smoothly. In 1957 Sterling and a group of mountain climbers from the Washington, D.C., area planned an extensive expedition into the mountains of Western Canada just prior to the annual meeting of the Plant Physiologists, which was being held at Stanford University that year. Sterling arrived at those meetings a day or two late. He wore a body cast on the upper half of his body, with the excuse that he had taken a bad spill. It was learned later that the group, while roped together, had plunged some 250 feet down the side of the mountain. Sterling, who had a cracked vertebra and a broken shoulder joint but was still ambulatory, went for help. The journey out over rugged terrain involved two rappels and almost two days travel. The night was spent in bivouac on snow and ice, with no food and inadequate clothing. He had left his food and clothing behind so that

the others might survive. He came to the meetings directly from the hospital; if it hadn't been for the upper body cast, it is doubtful that anyone would have known what had happened.

Sterling married Edith Ochiltree of Philadelphia in 1931. They were visiting their daughter, Martha O'Neill, and her family, including two grandchildren, in Novato, California, during the Christmas holidays in 1980. Sterling came down with the flu and took a vaccine shot in an effort to minimize the symptoms. He died shortly afterwards, on January 4, 1981, of the Guillain-Barré syndrome. At the time of his death he was still young in spirit, full of creative ideas, and deeply involved in productive lines of research.

WE ARE INDEBTED TO DR. LINUS PAULING for having had access to the biographical memoir of Sterling Hendricks he wrote for *The American Mineralogist*.

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