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SAMUEL COLVILLE LIND

1879—1965

A Biographical Memoir by

KEITH J. LAIDLER

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S. C. Lind

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June 15, 1879–February 12, 1965

BY KEITH J. LAIDLER

SAMUEL COLVILLE LIND was distinguished for his work on the kinetics of chemical reactions of various kinds, especially reactions induced by ionizing radiation. He is still particularly remembered for his early pioneering study, with Max Bodenstein in Leipzig, of the reaction between hydrogen and bromine. His later research and his books were significant in placing on a firm basis the effects of radiation on the rates of reactions. He had wide experience in government laboratories and universities, and through his engaging personality exerted a strong influence on others. His interests ranged far outside science, and his memoirs, published posthumously in 1972, shed an interesting historical light on the various institutions and people connected to him.

Lind was held in high regard as a scientist, teacher, and administrator. The esteem and affection of his friends and colleagues are evidence of his generosity and helpfulness. He had a lively sense of humor, and enjoyed jokes on himself. His friends ran the gamut from backwoods countrymen he met on his many fishing trips to Nobel laureates.

EARLY LIFE AND EDUCATION

Samuel Lind was born on June 15, 1879, in McMinnville, Tennessee, a town at that time of 2,000 inhabitants on the middle Tennessee plateau just west of the Cumberland Mountains. His father Thomas Christian Lind was born in Sweden and came to the United States at the age of nineteen. He served in the federal army in the Civil War, rose to the rank of captain, and was wounded in the Battle of the Wilderness. He was employed by the Pennsylvania Oil Company and was sent to Tennessee to find oil, but unable to find any, he studied and then practiced law. In May 1878 he married Ida Colville, a native of McMinnville, who belonged to a Scottish-Irish family that had arrived from Maryland and settled in Tennessee several generations earlier. Samuel was the eldest of five children, only three of whom—all boys—survived to maturity.

Lind's education was in the public schools and high school of McMinnville, and he later considered it to have been excellent. In 1895, at the age of sixteen, he enrolled at Washington and Lee University in Lexington, Virginia. This was a traditional, intensely Southern institution that emphasized the classics, but required its students to study mathematics and science. Lind spent most of his first three years studying French, Latin, Greek (which he took for four years), German, and Anglo-Saxon. He then entered his senior year needing six credits in science, and was persuaded that the easiest way to gain them was to take chemistry! He later commented that he had been forced by circumstances into what was to become his life's work.

Previously he had known little chemistry, but thanks to the inspired teaching of Jas Lewis Howe he found the subject entrancing ('Jas' was not an abbreviation). He later wrote that no praise could be too high for the teaching of Howe, who taught all the chemistry courses. After receiving his B. A. degree at the end of his fourth year, Lind decided to return to Washington and Lee for additional courses in chemistry taught by Howe. He also took courses in geology and mineralogy.

In the fall of 1902 Lind entered the Massachusetts Institute of Technology, where he took some courses and acted as a teaching assistant. At the time, MIT gave no graduate degrees, but he carried out some research under the direction of Arthur Amos Noyes and published his first paper. In the following year he was awarded a Dalton traveling fellowship, and decided to go to the Institüt für Physikalische Chemie in Leipzig. In preparation for this he spent three months in a *pension* in Kassel learning German, avoiding as far as possible any contact with English-speaking people.

THE LEIPZIG LABORATORY (1904-1905)

At this time the institute at Leipzig, directed by the eminent Wilhelm Ostwald, was world famous for its contributions to physics and physical chemistry. Students flocked there, particularly from the United Kingdom and the United States. Indeed, the institute was more renowned outside Germany than within, since at the time, German chemists concentrated on organic chemistry and many were hostile to the kind of chemistry done by Ostwald and his associates. Of the American chemists who were at Leipzig at about that time, eleven were later elected to membership in the National Academy of Sciences (Wilder D. Bancroft, William C. Bray, Frederick G. Cottrell, George A. Hulett, Arthur B. Lamb, G. N. Lewis, S. C. Lind, A. A. Noyes, T. W. Richards, E. C. Sullivan, and Willis R. Whitney), and six became presidents of the American Chemical Society (Bancroft, Lamb, Lind, Noyes, Richards, and Whitney).

In 1903, when Lind arrived in Leipzig, Ostwald's personal influence was on the decline, but he had two distinguished associates, Professors Robert Luther and Max Bodenstein. Most of the students went first to Luther for guidance, and he advised Lind to approach Bodenstein as a possible research director. In doing so Lind made a mistake, due to his limited knowledge of the language. He had intended to say, “Herr Dr. Luther hat mich empfohlen Sie zu besuchen (has advised me to see you),” but said instead, “hat mich befohlen (has ordered me).” He at once recognized his mistake and was embarrassed, but Bodenstein was amused, and later enjoyed telling the story. The two had a most profitable association, and got on well except for one unfortunate incident. Lind was boiling chromic acid, a highly corrosive liquid, and Bodenstein entered wearing for the first time a new, elegant spring suit. The beaker cracked, spilling acid over the suit, and Bodenstein only escaped serious injury by quickly dousing himself with water. Bodenstein was at first angry with Lind, but soon realized that he was in no way to blame. Frau Bodenstein later told Lind that the suit had been reduced to shreds.

Lind’s first research with Bodenstein was on the kinetics of the reaction between hydrogen and chlorine, but they abandoned the work on finding that there were serious experimental difficulties (which were not to be resolved until some years later). Bodenstein had already made important investigations on the reaction between hydrogen and iodine, which had proved to be much easier to handle; the rate of the reaction is directly proportional to the concentrations of hydrogen and of iodine (in the language of kinetics, the reaction is second-order). Bodenstein and Lind then turned their attention to the reaction between hydrogen and bromine, and found that satisfactory measurements of the rates could be made under a variety of conditions of temperature and reactant concentrations. The reaction was not, however, of the second order. The rate was proportional to the concentration of hydrogen, but not to the concentration of bromine; instead it was proportional to its square root. They also found that the reaction is inhibited (i.e., its rate is reduced) by the product of the reaction, hydrogen bromide. Their work led them to a fairly simple equation for the rate of reaction as a function of concentrations.

Bodenstein and Lind's paper on this reaction, published in 1907 in the *Zeitschrift für physikalische Chemie*, had an important influence on the course of chemical kinetics over the next two decades. Bodenstein was unable to give a detailed explanation for the peculiar kinetic behavior of this reaction, but he did in 1913 make the correct general suggestion that a chain reaction was involved. In 1918 Walther Nernst suggested a specific chain reaction for the more complex reaction between hydrogen and chlorine, but only later did his idea lead to the correct detailed mechanism. In 1919 and 1920 J. A. Christiansen, K. F. Herzfeld, and M. Polanyi independently and almost simultaneously proposed a specific mechanism for the hydrogen-bromine reaction and showed that their mechanism led precisely to the kinetic equation Bodenstein and Lind had obtained for the reaction. Their experimental work was therefore crucial to the evolution of the understanding of chain reactions.

The Leipzig Ph.D. degree (magna cum laude) was conferred on Lind in August 1905 on the basis of his work on the hydrogen-bromine reaction. Bodenstein offered him an assistantship in the Leipzig laboratories, but he decided instead to return to the United States.

UNIVERSITY OF MICHIGAN (1905-13)

In September 1905 Lind accepted an instructorship in chemistry at the University of Michigan. He was put in charge of the physical chemistry teaching laboratory, and was able to carry out a little research. An important change in his research career came in 1910, when he spent some months in the laboratories of Professor Marie Curie in Paris. He did not have much personal contact with her, but he attended her lectures. In the laboratories he gained a proficiency in the handling of radioactive substances and carried out measurements of the charge on the alpha particles. In the spring of 1911 he moved to Vienna to the newly formed Institüt für Radiumforschung, which was under the direction of Professor Stefan Meyer. There he worked on the formation of ozone from the action of alpha particles on oxygen molecules. Within three months he had been able to show that the number of ozone molecules formed is equal to the number of ion pairs produced in oxygen by alpha particles.

On his return to the University of Michigan, Lind wanted to continue this line of experimental research, but he was frustrated by the difficulty of obtaining radium. Instead, he carried out a detailed analysis of results obtained in England by Sir William Ramsay and associates and in 1912 published an important paper in which he clearly enunciated many of the basic principles that apply to chemical reactions induced by ionizing radiation. This was to be his main field of research for the remainder of his career.

U.S. BUREAU OF MINES (1913-25)

In 1912 the U.S. Bureau of Mines began to investigate, as a source of radium, Colorado carnotite, which is a potassium uranium vanadate deposited in sandstone. The work of the bureau was directed in Washington by Charles A. Parsons, chief chemist of the bureau. The fieldwork in Denver, Colorado, was directed by Richard B. Moore, who had studied under Ramsay. Because of his interest in radiation chemistry, Lind accepted in 1913 an appointment with the bureau, and worked at the Denver laboratory. Initially his work was mainly concerned with the extraction and refinement of radium from carnotite, and he published a series of papers on that subject from 1914 to 1920. The work was extremely laborious and was accompanied by some danger from radioactive emissions not fully recognized at the time. The ore contained only a few percent of uranium, and the ratio of radium to uranium was minute. From about 30 tons of uranium oxide obtained from the ore the Colorado institute produced 8.5 grams of radium. Of this, half a gram was entrusted to Lind, and he made good use of it in his experiments over the years, even after his retirement. Being unaware of the dangers of handling radioactive substances, Lind habitually picked up samples with his fingers, and the thumb and index finger of his right hand were burned to half their normal thickness, so that they left no fingerprints. Aside from a decrease in sensitivity in these two digits he suffered no ill effects.

On January 24, 1915, Lind married Marie Holladay of Omaha, Nebraska, and she subsequently accompanied him on all his travels.

After the completion of the separation work, Lind was transferred in 1917 to the Bureau of Mines station in Golden, Colorado, where he devoted much of his time to studying the chemical effects of radiation. For many years much of the work was done in collaboration with D. C. Bardwell. The reaction between hydrogen and oxygen is so slow at ordinary temperatures that no change can be detected, and Lind was the first to observe that reaction occurred at a measurable rate when radon was added as a source of alpha radiation. Lind carried out an important series of investigations on this reaction. He showed that the amount of reaction that occurred was directly proportional to the ionization produced in the gas mixture. He also showed that recoil atoms induce chemical action proportional to the ionization they produce. He also carried out a number of investigations on the influence of inert gases on chemical reactions induced by radiation, finding that reactions are accelerated as a result of the additional amount of ionization produced in the inert gas.

His investigations led him to a number of important conclusions. He was perhaps the first to recognize that chemical reaction is initiated at the centers at which the ions are neutralized. He concluded that in the hydrogen-oxygen reaction, both the hydrogen and oxygen molecules are separately activated by absorption of energy from the alpha rays. He found that about one-half of the energy released by an alpha particle produces a positively charged molecule, by eliminating an electron. Some of the rest of the energy is concerned with the direct formation of atoms or free radicals. The positive molecular ions produced undergo neutralization on encountering other species and are then highly energized and capable of undergoing further reaction.

Lind found that the ion yield—the number of water molecules produced per ion pair in the hydrogen-oxygen reaction—is about four. He interpreted this as due to the clustering of neutral molecules about the ions by electrostatic attraction. During this period he began to write his first book, on the chemical effects of radiation; it was published in 1921.

In 1920 the scientists at the Golden laboratories were transferred to Reno, Nevada, where they first worked in temporary quarters provided by the University of Nevada and later in a building constructed for them on the campus. One of Lind's investigations in Reno was on the coloring of diamonds by radiation, an effect first reported in 1904 by Sir William Crookes. Lind confirmed that diamonds exposed to alpha radiation acquire a brilliant green color and found that the coloration could be conveniently produced by exposure to radon gas. Green diamonds are extremely rare and their prices fabulous. Many diamonds have an unpleasant yellowish tinge, and are worthless as jewelry.

The yellow color was masked by the green tinge produced by radiation, and at first it was thought that diamonds of high value might be produced from worthless ones. It was realized, however, that the artificial green diamonds were very radioactive and therefore unwearable. Something of a stir was created in the jewelry world by the prospect of unscrupulous dealers making fortunes by selling radioactive diamonds. After a famous jewelry firm had treated Lind with some hostility, he decided to carry out no further experiments on this sensitive matter; he did, however, think his results were of scientific interest, and he and Bardwell published an account of them in 1923.

In that year Lind was appointed chief chemist of the Bureau of Mines; this involved a move to Washington, and Bardwell went with him. There the two continued their experimental work in radiation chemistry.

FIXED NITROGEN RESEARCH LABORATORY (1925-26)

In 1925 Lind resigned his position at the Bureau of Mines to become assistant director of the Fixed Nitrogen Research Laboratory of the U.S. Department of Agriculture. The laboratory was in Washington, and the director at the time was F. G. Cottrell, who agreed to appoint Bardwell also.

At this laboratory Lind worked on the radiation chemistry of a number of reactions, including the oxidations of saturated and unsaturated hydrocarbons, the hydrogenation of unsaturated hydrocarbons, and the reaction between carbon monoxide and oxygen. He and his assistants also did further work on the influence of inert gases on radiation-induced reactions.

UNIVERSITY OF MINNESOTA (1926-47)

In 1926 Lind was offered two important academic positions almost simultaneously: to be head of chemistry in two of the most prominent mid-western universities—Michigan and Minnesota. His decision to go to Minnesota was largely because the position offered was head of its School of Chemistry, which was not part of any other faculty and included a very effective department of chemical engineering. Also, the University of Minnesota was a prestigious one; it had a particularly strong administrative structure and had been presided over by men of great distinction.

Lind's twenty-one years at the University of Minnesota were very effective, as he did much to enhance the already high reputation of the school. He soon made a number of wise appointments, one of which was to bring Isaak Kolthoff from the University of Utrecht to be head of analytical chemistry; from 1927 until his retirement in 1962 Kolthoff, by his books and research, made the University of Minnesota a leader in the field. Lind also brought in Frank McDougall to be in charge of physical chemistry, and he in turn appointed a number of people who were to distinguish themselves and the University of Minnesota for the quality of their teaching and research. Among them may be mentioned George Glockler and Robert Livingston (with both of whom Lind later collaborated), Hubert Alyea, and Bryce Crawford. Later Alyea, particularly after going to Princeton, became famous throughout the chemical world for his lecture demonstrations. Bryce Crawford became well known for his pioneering contributions in chemical spectroscopy, and later became dean of the graduate school at the University of Minnesota.

Lind was also active in a number of ways outside his university. He was elected president of the American Electrochemical Society in 1927 and the American Chemical Society in 1940. In 1932 he assumed the editorship of the *Journal of Physical Chemistry*, which had fallen into ill repute as a result of the old-fashioned ideas of its founder and former editor Wilder Dwight Bancroft (A. A. Noyes did not allow the journal in the chemistry library of the California Institute of Technology). Previously the papers published in this journal were in certain narrow and unimportant branches of chemistry and were sometimes written by cranks with outmoded ideas. Lind at once tightened the editorial policies, and the journal soon became a more important medium for the publication of high-quality research.

Because of his many other activities Lind's research output during his years at the University of Minneapolis could not be as great as in previous years. He nevertheless directed an extensive research program in the field of radiation chemistry, and a number of students earned their Ph.D. degrees under his direction. He always maintained an active interest in research, and in 1939 he published, in collaboration with George Glockler, a book on radiation chemistry that exerted a wide influence.

LATER YEARS

Lind retired from the University of Minnesota in 1947 at the age of sixty-eight. In the following year he attended a meeting at Oak Ridge in his native Tennessee, and he and his wife decided to make their home there. In July 1948 he was appointed a consultant to the Union Carbide Corporation, which had the contract under the Atomic Energy Commission to run the plants and laboratories at Oak Ridge. He obtained the necessary security clearance and first worked in the gaseous diffusion plant, which was concerned with the separation of uranium-235—the fissionable isotope of uranium—by gaseous diffusion of its hexafluoride.

For a period Lind served as acting director of the chemistry division at the Oak Ridge National Laboratory and for several years he actively continued his research on the radiation chemistry of gases. In 1957 at the age of seventyeight he published a significant paper with Philip S. Rudolph on the polymerization of acetylene under the action of alpha radiation. Other radiation-induced reactions studied with Rudolph were the polymerization and dissociation of carbon monoxide.

Lind had a great love of trout fishing, and his memoirs include many stories of fishing incidents and entertaining accounts of several minor brushes with the law, leading to fines as a result of unintentional violation of fishing regulations. It was while trout fishing in the Clinch River below Norris Dam that he met his death on February 12, 1965, at the age of eighty-six. After he had been reported missing, his body was found a mile downstream from where he had been fishing, waters from the dam having carried it there. For some years Lind had been quite deaf and had to wear a hearing aid, which he would often say was a boon to him, as he could turn it off if a conversation became boring. His deafness perhaps contributed to his death, as he may not have heard the rush of the waters unexpectedly released by the dam. He was buried in McMinnville, where he was born; Marie, his wife of just over fifty years, survived him.

Lind was awarded many honors. In 1926 he received the Nichols Medal of the New York section of the American Chemical Society. He was elected a member of the National Academy of Sciences in 1930, the only native Tennessean to have won that distinction. He was elected a member of the Minnesota Academy of Science in 1940 and the American Philosophical Society in 1943. In 1949 he was elected to the Tennessee Academy of Science, and in 1952 the American Chemical Society gave him its highest honor, its Priestley Medal. He was awarded honorary doctor of science degrees by the University of Colorado in 1927, Washington and Lee University in 1939, the University of Michigan in 1940, and the University of Notre Dame in 1963.

I NEVER MET LIND, and I prepared this memoir to some extent on the basis of his autobiography, which was published posthumously (1972). It contained an appreciation written by Philip S. Rudolph and a description of the circumstances of Lind's death. The Academy provided me with other information, including an unpublished memoir prepared by Lind in 1943; this carried a complete list of his publications up to that time. Some valuable background material, especially about the Leipzig laboratory, was provided by John W. Servos in his book *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America* (Princeton: Princeton University Press, 1990). I am particularly grateful to Professor Bryce Crawford, who knew Lind at the University of Minnesota, for his unfailing support and helpful suggestions.

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