NATIONAL ACADEMY OF SCIENCES

FRANK HAROLD SPEDDING
1902–1984

A Biographical Memoir by

JOHN D. CORBETT

Biographical Memoirs, VOLUME 80

PUBLISHED 2001 BY
THE NATIONAL ACADEMY PRESS
WASHINGTON, D.C.

Courtesy of Ames Lab

FRANK HAROLD SPEDDING

October 22, 1902–December 15, 1984

BY JOHN D. CORBETT

FRANK HAROLD SPEDDING is recognized and honored for the impact he had on understanding of spectra of the rare-earth elements; for the major leadership and scientific role he played in important process development and production of pure metals during the war, especially uranium and thorium; for the separation of the rare-earth elements and provision of them as high-quality salts and metals; for major scientific studies of many aspects of the chemistry and physics of rare-earth compounds; for the establishment of a national Ames Laboratory for the U. S. Atomic Energy Commission (now Department of Energy).

Frank Harold Spedding was born on October 22, 1902, in Hamilton, Ontario, to Howard Leslie Spedding and Mary Ann Elizabeth (Marshall) Spedding. Soon after his birth the family moved to southeastern Michigan and then to Chicago. In 1918 they moved to Ann Arbor, Michigan, where his father set up shop as a photographer. Spedding matriculated at the University of Michigan in the fall of 1920, from which he subsequently received a B.S. degree in chemical engineering in 1925 and an M.S. degree in analytical chemistry in 1926. From there he went to the University of California, Berkeley, from which he obtained a Ph.D. in physical chemistry in 1929 under Professor Gilbert N. Lewis.

As an undergraduate at Michigan, Frank Spedding displayed the curiosity and creativity that was to be the hallmark of his life as a first-class researcher. He found the then current explanation for how the six carbon atoms in benzene were held together unconvincing and came up with a different scheme of his own. This was prior to the application of quantum mechanics to chemical problems, and the prevailing bonding theory was mainly that of E. A. Kekulé. Spedding took his model to Professor Moses Gomberg, from whom he had taken a class, and Gomberg immediately recognized his model as that proposed by Professor A. Landenburg in 1869 during the much heralded debate between Victor Meyer, Kekulé, and Landenburg. Spedding switched to analytical chemistry for his M. S. after he had worked as an undergraduate co-op student at a local industry. It was the foregoing association with Gomberg that led Spedding to the University of California at Berkeley. Gomberg not only recommended that he go to Berkeley but he also put in a good word with G. N. Lewis so that he was accepted and given a teaching fellowship in physical chemistry. Lewis became his major professor, and Spedding felt he had arrived in a young chemist's heaven.

Spedding's research during graduate school years was spent learning about electronic spectroscopy, especially absorption spectra. Spedding's first publication with Simon Freed (1929) had to do with line absorption of solids at low temperature in the visible and ultraviolet regions. This was also a time when his interest in the rare-earth elements was whetted. Later publications with Freed made comparisons of the spectral properties of crystalline halogen compounds of samarium and gadolinium. Spedding was also put to work testing some of Lewis's theories and found that the first three or four turned out to be "wild goose chases." However, the experiments gave valuable experience, leading

Spedding to the conviction that, although a genius may have 10 ideas but only one success, a large part of the success ordinarily attributed to genius was the result of sheer hard work and an ability to overcome frustrations.

Spedding finished his research for his Ph.D. in 1929 and was greeted by the Great Depression. Jobs for chemists were virtually nonexistent, and so for the next seven years he lived on promises and a series of temporary fellowships. Although these carried prestige and honor, they were financially meager and offered at best only a hand-to-mouth existence. The stress of the period probably produced the ulcer that plagued him much of his life. For the years 1930-32 Spedding was awarded a National Research Fellowship, which enabled him to stay on at Berkeley doing full-time research. After that, Lewis hired him as a temporary chemistry instructor for 1932-34 with his main duties being continued research on the absorption spectra of solids.

It was during this time that Spedding started to integrate ideas from the newly developing quantum mechanics into his chemical thinking and his spectroscopic studies of atomic and molecular structure. It was already well established that gaseous elements gave sharp-line spectra, whereas liquids and solids generally did not. However, it was already known that the rare-earth-containing mineral xenotine did exhibit sharp lines when cooled to ~80K, which Spedding reasoned was because of the unusual electronic structure of the rare-earth constituents. But *pure* rare-earth compounds were scarce and almost impossible to obtain even in small amounts. Professor B. Smith Hopkins of the University of Illinois had a small supply of some rare-earth salts in relatively pure form, so Spedding appealed to him for a loan of a few tenths of a gram with the promise that it would not be consumed in any way. “I practically went down on my knees to Dr. Hopkins,” is the way Spedding told the story, and he did get the loan. The samples gave sharp lines, and Spedding went on to show that their fine structure depended upon the symmetry of neighboring atoms or molecules in their crystals, and this enabled him to determine the symmetry of various crystals (1931). It was for this work that he was presented with the Langmuir Award in 1933, then given to outstanding young chemists who had not yet reached 31 years of age. Only Oscar K. Rice and Linus Pauling preceded him in this achievement. The award was thereafter changed to the Award in Pure Chemistry of the American Chemical Society and the age limit was raised to 35.

Frank Harold Spedding and Ethel Annie MacFarlane were married on June 21, 1931. She had been born in Winnipeg, Manitoba, graduated from the University of Saskatchewan in 1919 with distinction, and received a further master's degree in history from the University of Toronto. She was teaching at Victoria High School, Victoria, British Columbia, when she and Frank Spedding met while hiking in northern California. They took up housekeeping during his tenure of the National Research Fellowship and under rather Spartan conditions. He related that their greatest source of pleasure and recreation was in the great outdoors, camping, hiking, and mountain climbing, because it was what they could afford. They later had a daughter, Elizabeth.

The Langmuir Award in 1933 was bestowed at the Chicago World's Fair. This exposition dramatized the progress in technology during the first 100 years of the city's existence, and his award was an appropriate showpiece for the exposition. Spedding was to give a talk describing his work and so he borrowed money in order to travel to Chicago. After he was introduced, he related, "I froze and could not remember how to get started." He went on to say that he was struck dumb for an interminable time, actually perhaps only ~10 seconds, and then he called for the first slide. The talk went off without a hitch thereafter and was greeted by a pleasant round of applause.

At the end, after answering a question or two and the award presentation, an elderly gentleman made his way up to the platform. Spedding relates that the man's appearance reminded him of a then current comic strip character called "Foxy Grandpa," short, bald, and with a long white beard. Getting Spedding's attention, the man blurted out, "How would you like to have a pound of europium and two or three pounds of samarium?" (These were among the scarcer of the rare earths and were ordinarily obtainable only in milligram quantities.) Spedding said, "I thought this guy was crazy," but "I was polite to him and agreed that it would be fine and would help to further my work." Not long after his return to California a box arrived containing fruit jars of europium and samarium oxides. It was then that he found out that his benefactor was Herbert M. McCoy, a retired professor of chemistry at the University of Chicago. McCoy had earlier succeeded in separating some of the rare earths by fractional crystallization, as had Hopkins. When he further learned that Lindsey Light and Chemical Company had a supply of residues containing these elements left over after thorium extraction, that europium could be reduced to the divalent state and as such easily separated from the other elements, and that a related process had been developed for the neighboring samarium, he arranged to work up some of these rare-earth-metal residues. He was very generous according to Spedding and gave deserving people such quantities of europium compounds. (Spedding's life was to be influenced again by H. M. McCoy about nine years later in his career.)

The Langmuir Award included not only a gold medal but also an honorarium of $1,000, a lot of money in 1933. This augmented his University of California stipend, so he and Ethel looked forward to an easing of their lives in Berkeley. However, the depression was becoming more severe, universities were hardly able to pay their faculty, and G. N. Lewis was likewise hard pressed to support other promising potential staff members. Spedding recounts being called into Lewis's office during the 1933-34 academic year to be greeted by, "Now that you won your $1,000, you won't need all the money we're paying you, so your salary for the year will be cut by $500." Still no jobs were to be had, so he applied for and received a then rare Guggenheim travel grant for the year 1934-35. He planned to spend part of the time abroad, working in Germany with James Franck, a Nobel Prize winner, who had made a brief visit to Berkeley, and also part-time with Professor Francis Simon, a leading low-temperature physicist. Germany had by then come under Hitler, and Franck and Simon, both Jews, had fled to Denmark and England. Frank and Ethel went instead to England. He was warmly received at the Cavendish Laboratory in Cambridge by Ralph Fowler, professor of theoretical physics, and while there had the chance to work with John E. Lennard-Jones in quantum mechanics, meet Max Born who had also left Germany, and attend Born's seminars.

Travel expenses were to be paid by the Guggenheim Foundation, but the first quarterly payment would have had Frank and Ethel arriving in Europe with little left on which to live. Frank found that they could travel on a Japanese liner across the Pacific and then on other ships to England for less than half the quoted fares across the United States and the Atlantic Ocean. Spedding relates that their tourist-class tickets restricted their shipboard quarters only until they were beyond land; at that point they were allowed free access to all parts of the ship. "The captain was all too happy to have paying customers aboard," so the story went. There were leisurely stopovers in Japan, China, Malaya, and

Ceylon; they sailed up through the Red Sea and the Mediterranean and finally landed in Southampton about four months after leaving. The young couple profited immensely by their roundabout route to England: no charges for food or lodging all the way and immeasurable experiences to boot.

Abraham F. Joffe, a Soviet physicist whom Spedding had met in Berkeley and knew was in England, invited him to lecture in Leningrad, Moscow, and Kharkov at the expense of the Russian government. With some reservations, the Speddings accepted. Frank lectured at Leningrad but for unknown reasons never went to the other cities. Being in Europe had other advantages for the young scientist. There were side trips to the Netherlands to visit Kamerlingh Onnes's low-temperature laboratory, to research laboratories in France, Germany, and Latvia, and to Copenhagen to visit Niels Bohr. Bohr was a kindly man and greeted the then unknown young scientist warmly. Spedding liked Bohr not only because he treated Spedding as a friend but also because of his "brilliant mind." Bohr's English was difficult to understand, and "one really had to listen to him twice," according to Spedding, "but there was no doubt about his grasp of a subject." He spent a month in Bohr's institute, and although he did some theoretical work, he was determined to be an experimentalist and so he left. After the Guggenheim Fellowship ended, the Speddings felt they had to get back to the United States to look for a position that would pay a regular stipend. They returned to his parent's home in Michigan full of grand experiences but in dire need of a permanent job.

Canvassing the job market for a permanent position proved fruitless, but the George Fisher Baker assistant professor position at Cornell University was open, so Spedding took yet another temporary position, this time from 1935-37. Spectroscopic studies of other crystalline compounds of samarium continued there and were expanded to compounds of thulium, gadolinium, neodymium, erbium, and praeseodynium. During this time, working with Hans Bethe, Spedding showed conclusively that the sharp lines observed in the absorption spectra of rare-earth compounds arose from their inner shells and originated with 4f transitions (1937).

The entire period between 1930 and 1937 had been an enriching one for Spedding. He had also studied the effect of magnetic fields on the sharp lines in crystals and how they affected energy levels, and had done some spectroscopy in assisting G. N. Lewis in his efforts to concentrate deuterium. This work was described in his only publication bearing G. N. Lewis's name.[1] Spedding also used spectroscopic techniques to add another significant figure or two to the value of *e/m*, the charge-to-mass ratio of the electron, and to determine a better value for *a*, the fine structure constant. The broad scope of Spedding's spectroscopic studies at the time made him one of the premier electronic spectroscopists in the country and also one of the country's experts in the chemistry of rarer elements. Thus the next period in his life was set.

As the position at Cornell was winding down, he was again on the job market. After following several unproductive leads, he heard about a chance for a tenure-track position at Ohio State University, so he and Ethel got into their old Chevrolet and drove to Columbus. There an interview with Professor W. L. Evans, then head of chemistry, proved to be another frustration because Evans had just hired a new physical chemist. However, Evans knew that his friend Winfred F. (Buck) Coover at Iowa State College had lost much of his physical chemistry staff from resignations stimulated by greener pastures and was looking for a replacement. (Frank is quoted as saying, "I wouldn't normally have chosen the place, but I was desperate. I thought: I can go there and build up physical chemistry and when jobs really open up I can go to another school.") Again the Speddings trekked west.

An interview with Coover was encouraging in that Spedding was offered an assistant professorship on the spot. Although this was one step above the instructor rank at which young staff members were hired at Iowa State, it still was no assurance of anything more than a three-year appointment, subject to review before possible promotion to associate professor with tenure. Spedding already had seven years of uncertain positions behind him, so he asked for an associate professorship from the onset. Coover could not offer him this without consultation with college administrative officers and the regents. The situation was left that way, with the Speddings continuing to head west. They hoped to stop at Yellowstone National Park for several days on their way, and Coover was to wire him in care of general delivery at the Yellowstone Lodge. Several days followed and no wire. On the day Frank and Ethel were to leave the park, a last-minute check produced the wire from Coover. Spedding's name had been garbled in the address, but the associate professorship with tenure had come through. So in the fall of 1937, the Speddings checked into Ames, Iowa, where he became the head of the physical chemistry section of the Chemistry Department at Iowa State College.

There was meager modern equipment at Iowa State when Spedding got there. Funds were very tight, but some money was made available for a good ruled grating to be mounted on a Rowland circle in the basement of the chemistry building to enable him to continue his spectroscopic studies. Meanwhile, he changed the rest of his research program to a type of chemistry possible with equipment available at the college. Since he earlier had great trouble getting even small amounts of pure rare-earth compounds, Spedding started a program to separate adjacent rare earths from one another, looking for a process that would automatically repeat the enrichment interaction thousands of times and do this rapidly. He thus had his students work on problems involving chromatographic columns with various forms of aluminum oxide or silica gel absorbers, but they had very little success with the separations. They also explored paper chromatographic methods that were being developed at that time, but these too were not very successful. This work was interrupted by the onset of World War II and was never reported in the literature.

By this time World War II had already started in Europe and select scientific circles recognized the possibility of a nuclear fission bomb with ^{235}U if the chain reaction problem could be solved. Accordingly, in what is a well-known story, the U.S. government decided to become active in this research program, and scientists who knew something about the subject were gathered at three research centers at the University of California, Berkeley; Columbia University; and the University of Chicago. Professor A. H. Compton of the University of Chicago was put in charge of the last, with the object of seeing whether a nuclear chain reaction could be achieved with natural uranium. In December 1941, the month of Pearl Harbor, Compton decided that the physicists needed chemists to help them in this program, and he asked his chemist friends to suggest outstanding inorganic chemists in the country who also knew something about the rarer elements, particularly uranium and the rare-earth elements. He learned of Spedding from H. M. McCoy, and from the list of names suggested, invited Spedding in February 1942 to head the chemistry program in the Chicago program. G. Seaborg (Berkeley), C. Coryell (MIT), M. Burton (Notre Dame), and G. Boyd (Oak Ridge) became involved in various chemistry sections.

After Spedding acquainted himself with the chemical problems, he informed Professor Compton that he had some space available at Iowa State College in Ames, and that he could enlist a number of his associates to help. It was then decided that Spedding would spend half of each week in Ames, working with his group there to solve some of the immediate chemical problems, and the other half of the week in Chicago organizing the chemistry division. (A recollection of a new student who entered Iowa State in the fall of 1941: "I took physical chemistry from Dr. Spedding. During the fall quarter he was a well-prepared and effective teacher. After the Christmas break, he was less organized and often came into the lecture hall opening his copy of the text and asking what page we had stopped on in the last class period. It was much later that I discovered that his lack of preparation was due to his spending most of his time on a special research project in Chicago.")

One of the most pressing problems was to get materials that were pure enough to build a nuclear reactor at Stagg Field, Chicago, in which the chain reaction would have a chance of going critical. Because of the small amount of ^{235}U in ordinary uranium, the reactor would have to be built to very exacting specifications, and the materials (uranium and graphite in particular) would have to be of exceptional purity, since many expected impurities were known to absorb neutrons. Therefore, one of the great needs of the program was to find a process that could produce ultra pure uranium metal in large quantity. Very little uranium metal had been produced prior to that time. Westinghouse and Metal Hydrides agreed to step up their processes and to supply Chicago with uranium metal. However, the metal from these sources was very slow in coming to Chicago and was cast or compacted into very small blocks—1-inch cubes or smaller—that were not very pure at the beginning. All handbooks published prior to 1942 reported the melting point of what must have been quite impure uranium to be ~1800°C, whereas it was later shown that the pure metal melted at 1132°C.

One immediate need was a source of a pure uranium compound as input to any process of metal production. While it had been known for a long time that uranium could be purified by an ether extraction from an aqueous solution of uranyl salts, the course of various impurities in the process was not well known. One of the first problems for Boyd's group at Chicago was to determine whether uranium so extracted would be satisfactory with regard to purity, and they reported that the method looked very promising. Spedding reported to Compton that they ought to arrange for the ether separation instead of other alternatives. As a result Compton and Spedding visited the Mallinckrodt Chemical plant in St. Louis, the chief manufacturer of ether, to contract for the solvent extraction work. At that time not many people were anxious to scale up this process since it was inherently *very* dangerous. Unless the plant was carefully designed, it would very likely burn down before much pure uranium was produced. While Compton spent his time at St. Louis discussing contract terms with Mr. Mallinckrodt, Spedding discussed with Dr. Ruhoff, superintendent of the plant, a flow sheet for the chemical engineering operations that would provide the necessary purity of uranium. Mallinckrodt accepted the contract, and Ruhoff with his staff designed the type of plant needed in detail. They did a remarkable job in building a plant that turned out large quantities of highly purified uranium oxide with minimal hazard in an exceptionally short time.

The groups at Chicago were very crowded for space at first; only a few rooms were available in the chemistry laboratories because other University of Chicago professors also had important programs connected with the war effort. At that time the so-called "Compton's folly" of trying to get energy from the atomic nucleus did not have too high a local priority. To get some of the chemical work underway immediately, the Office of Scientific Research and Development gave Iowa State College a letter of intent for a three-month contract in February 1942, with the understanding that, as soon as suitable space became available at the University of Chicago, Spedding would move his group to Chicago. Professors Harley Wilhelm and I. B. Johns of the Iowa State Chemistry Department joined him at Ames as associate directors. They immediately enlisted their graduate students, and this was the nucleus of a group that started the work, soon to be joined by other graduate students and professors in the department as the group grew very rapidly. Spedding later remarked that he was "very lucky" to have had Wilhelm on the team. The latter had completed a Ph.D. in physical chemistry 10 years before, was then head of the graduate program in metallurgical science in the department and also had extensive experience in analytical spectroscopy.

One of the first problems was material that would contain molten uranium. Although graphite was known to react with uranium metal, the Ames team soon found that most of the carbide formed remained at the interface between the metal and the graphite if the graphite container was kept at a temperature slightly lower than the molten uranium and not for too long. This made it possible to make large castings of uranium in which the carbon and oxygen content in the bulk was less than 0.02 percent or 0.03 percent by weight, and this was improved with time.

The Ames team initially tried to reduce uranium oxide to the pure metal using H_2 but did not have much success. But by August 1942 the Spedding-Wilhelm team had also worked out a process for the production of high-quality metal by a thermite-like reaction. A UF_4 sample had been circulated at a board meeting in Chicago (from the Y-12 isotope separation process at Oak Ridge), and it occurred to Spedding that this might be better than the troublesome oxide. This was successfully bomb reduced by calcium in a capped steel pipe lined with calcium oxide to prevent the ready U-Fe alloying reaction. In the month of November 1942 the process was scaled up, and two tons of high-purity uranium metal as machined cylinders, 2 inches in diameter and 2 inches long, were sent to Chicago, one-third of the six tons needed for the Stagg Field reactor. As a result, the Chicago group succeeded in achieving history with the attainment of criticality on December 2, 1942. Spedding was present on this occasion as director of the Chemistry Division of the Chicago Manhattan Project, as it was then called. By March 1943 the process had been improved so that magnesium could serve as a cheaper and purer reductant.

The ingots of uranium furnished from Ames were so much purer and less expensive than the uranium metal being produced by others that the Manhattan District asked three companies, Mallinckrodt, the Electrometallurgical Division of Union Carbide Co., and DuPont to produce large amounts of metal by this proces for other reactors. Their company scientists and technicians studied the Ames process and went back and started building facilities to produce the metal. In the meantime, the government asked Spedding and his coworkers to produce all the uranium metal they could. During the ensuing several months, more than 2 million pounds of uranium metal were produced at Iowa State College in a scaled-up pilot plant set up in a temporary wooden building the college inherited after World War I. A large amount of this metal was used in Oak Ridge to build the prototype plutonium production reactor. Other large amounts went to various sites around the Manhattan

Project for research and development work. The remainder went to Hanford to help build the first plutonium production reactor. This Iowa State work was all carried out on two floors in one quadrant of the chemistry building, partly in the former physical chemistry laboratory. Security was very tight, although remarkable sights were sometimes visible through the windows, particularly at night during casting operations.

In July 1943 these companies started producing metal, and Ames reduced its uranium production and then discontinued it by the start of 1945. It was the success of this effort that led to the decision not to move the Spedding-directed effort to Chicago. Even today, general commercial uranium production uses the Ames thermoreduction process as modified during scale-up.

Stories about this secret and rushed production abound. The effort involved around-the-clock shifts seven days a week and, with these reactive materials and a wooden building, fires were always a problem, but never seriously so. One "mysterious" explosion (or innovation) on the graveyard shift moved one wall of the building out a foot, although no record of the exact cause could be found. A former shift worker said that Spedding "often reminded us that we were being deferred from army service to work here, and therefore we were expected to put in many extra hours." Shipping the uranium ingots to Chicago involved some novel circumstances because of the metal's high density, 19.05 g/cm^3 (1187 lb/ft^3). An American Express driver needed help from two guards to lift a small (120-pound) crate containing the first two ingots. The driver first thought that someone had screwed the container to the desk. In addition, the locals wondered about "loaded" freight cars that seemed to go out nearly empty. Because of the intensive schedule, information meetings or "Speddinars" were held on Sunday mornings and later on Saturdays. Waste CaF_2 and uranium turnings were to be shipped off site for recovery. The need for watertight containers led a former Kentuckian to suggest white-oak barrels that had been used for aging bourbon, which were ordinarily destroyed after one use. Even though the central administration had been told to rush and not to question any purchases that Spedding requested, he was called to the university president's office to explain the order to Hiram Walker for "50 Barrels Bourbon" (with a missing comma, it turned out).

The demonstrated capabilities and expertise of the pure metals program were called on for other wartime production needs. A total of 437 pounds of very pure cerium was supplied in 1944-45 for the production of CeS crucibles used at that time in the plutonium program. Other concerns over whether there were sufficient uranium supplies led to the development of reactors to convert ^{232}Th to fissionable ^{233}U. A route to high-purity thorium metal was therefore developed on request, a more difficult problem because of both the melting point of the thorium, which is 500°C higher than that of uranium, and the greater stability of ThF_4, etc. Over 1944-46 a calcium reduction process "boosted" by added ZnF_2 together with the use of beryllia crucibles for vacuum casting at 1850-1900°C was developed. By December 1946 over 4,500 pounds of thorium had been cast and shipped to other sites.

After peace was declared in 1945 an Institute for Atomic Research was set up by Iowa State College with modest support from state funds, and Spedding became its director. The building constructed afforded space for the director, for administration, and a seminar room; a second floor Physical Sciences Reading Room; and in the basement Spedding's spectroscopy laboratories. However, the national need was recognized to reorganize the laboratories all over the country that had accomplished so much during Manhattan Project days under federal auspices. This was accomplished by the creation of the Atomic Energy Commission (AEC), whose objective was to fill in the gaps in research developed during the war years and to promote peaceful uses of atomic energy. In 1947 the Ames Laboratory of the AEC was set up on the campus of Iowa State, and Spedding became its director. Research at the Ames Laboratory at that time was considered by the AEC to be related to the development of nuclear power, and materials research along these lines was particularly encouraged. A strong emphasis on pure metals and their properties became a lasting feature. Spedding spoke on many occasions about his role in the Manhattan Project and the overall effort that led to the end of World War II. Although some other scientists later regretted their participation in such work, Spedding never expressed any misgiving or regret about his role. He evidently believed it was the "right thing to do," given the war in Europe and Asia.

The first permanent government building for the Ames Laboratory was completed in 1948 and a second in 1950. These are now named Wilhelm Hall and Spedding Hall, respectively. The first enabled the research housed in part of the chemistry building and in two temporary buildings elsewhere on campus to be consolidated into modern quarters, and the chemistry space was turned back to the college. An interesting remnant came with the reversion of space. As noted earlier, Spedding idolized his mentor, G. N. Lewis. The latter had a modest seminar room, a long table with seating for about 6 around it, plus a raised level around three sides with seats for 16 and a blackboard at the open end. Lewis and his senior grad students—and sometimes visitors—sat around the table with the junior grad students on the raised sides. Spedding had a very close copy of the seminar room constructed at Iowa State, but with a double row of seats on the elevated level. This was the faculty conference room in chemistry when I arrived in the early 1950s. Another similarity was that G. N. Lewis was a cigar lover and had a lighted one at hand all the time, and so too did Spedding. The latter would become very attentive during meetings with his students and senior scientists, and these onlookers would sometimes fear for Spedding's safety when he inattentively attempted to relight cigars, and put the used matches and ashes in his coat pocket. It was not unusual to find several partially smoked cigars around his office, some still lit! He was also reported to take the cigar out of his mouth and hold it behind his back when he took visitors into the calorimetry laboratory where they were making heat capacity measurements and venting gaseous hydrogen (with warning signs everywhere). Fortunately, the ventilation in the building was quite good!

Historically, separation of the rare-earth elements from one another had been difficult, owing to their very similar chemical properties. Chemists had succeeded in separating all of them in modest purity but in very small amounts by fractional crystallization, some cases requiring hundreds, even thousands, of separations. Among the major fission products of ^{235}U are the rare earths, namely the elements La-Lu and Y, and the very high neutron-capture cross-sections of some of these would inhibit any chain reaction after some U^{235} had been consumed. Samples of the individual members were needed so that both the nuclear properties related to the fission reactor as well as chemical processes that could separate them from unfissioned uranium and plutonium could be studied. Spedding's separation efforts were resumed in late 1944 by Jack Powell, Adolf Voigt, Elroy M. Gladrow, Norman R. Sleight, and others, who used citrate elution at high pH on ion exchange columns to separate adjacent rare earths in moderate quantities (1947, 1951). The separation with citrate as the complexant was really only effective for the lighter half of the rare earths where the inter-element differences are somewhat larger.

A major improvement in these separations was achieved later with a switch to EDTA as the complexing agent, leading to a pilot-plant-scale operation by 1953. This advancement resulted from a cooperative effort with Gerard Schwarzenbach (ETH, Zurich) who aided the measurement of the EDTA-rare-earth ion complex formation constants, and the recognition by Powell and Spedding that displacement ion exchange chromatography gave by far the best separations (1954). In some cases oxides were produced that contained only a few parts per million of all other metals. This was scaled up by request to produce kilogram quantities of all the rare-earths salts for general research purposes throughout the AEC laboratories and elsewhere. More than 80 commercial companies sent their scientists to Iowa State to study this process, and several set up plants to make these elements generally available. Once the rare-earth compounds became generally available to the general scientific community, many practical applications were found, and a considerable industry developed that involved the use of rare earths.

Parallel with this work, Spedding, Wilhelm, Adrian Daane, Wayne Keller, and others developed processes for producing very pure rare-earth metals in quantity (1952, 1953, 1958). During the early 1950s much interest in yttrium developed because it was a light, high-melting metal that formed a particularly stable hydride. Development of a nuclear reactor that could be used in airplanes was conceived in which the deuteride might serve as an ideal neutron moderator. Thus in 1954 and early 1955 the group produced tons of yttrium metal and further scaled up the methods already developed for producing kilogram quantities of the other metals. A process similar to one used for thorium was developed, namely co-reduction of the trifluoride with calcium and magnesium to form a low-melting Y/Mg alloy. The magnesium was sublimed from this alloy under high vacuum, and the resulting yttrium sponge then formed into acceptable billets by vacuum arc melting. By 1957, 20,000 pounds of cast Y metal had been produced at Iowa State along with 65,000 pounds of YF_3 that was supplied to commercial metal producers all over the country. Again the research group under the direction of Spedding was able to take a process developed on a laboratory scale and produce gross amounts of a needed commodity.

In this period Spedding also established extensive joint programs in fundamental solid-state physics and in metallurgy. The novel properties of many of the metals, salts, and their alloy systems were determined in these programs (1953, 1962). After about 1950 Spedding set up a program to study the thermodynamic, conductance, transference, etc., properties of electrolytic solutions of rare-earth salts, in part to enable fundamental considerations of a series of electrolytes that differed principally only in the radii of the cations. An extensive literature accumulated as a result (1952, 1954, 1959).

Graduate students' recollections of these busy and productive times are most illuminating and give real insights into the director as a person and as a scientist. His interests and abilities were very wide in scope, and he actively participated in the joint programs with physics and metallurgy. A major attitude that he passed onto students (and faculty) was his insistence on getting the physical picture behind any phenomenon or theoretical treatment. The power of critical thinking and the need (because of Spedding's busy schedule) to work independently came with these as well.

Spedding generated intense loyalty from his students, in part because they knew he generally spent more time at work than they did, and that was already at least 60 hours per week. One student commented on this when he found Spedding at work on a Sunday afternoon, to which his rejoinder was, “I would rather wear out than rust out.” Another student comment was that he had never heard of or seen Spedding lose his temper with or jump on anyone. But he could also be very firm, which included dealing with young outside visitors who thought the older administrator must be out of touch with science. Because of his bleeding ulcer, he had to go to the hospital for a blood transfusion every once in a while, but this was generally not known. One of his graduate students learned of this circumstance and commented that he would be glad to donate blood any time he needed it. “Oh God, no,” Spedding replied, “can you imagine how it would look if people knew I was taking blood from my students?”

Over the years Spedding published 260 scientific articles, a select 25 of which are listed at the end of this memoir. The nature of the Ames Laboratory research and development also led to 22 patents in his name and others, all of which were assigned to the U. S. government. A good measure of his educational efforts and contributions as well is the fact that 88 students received Ph.D. degrees under his guidance and tutelage.

Professor Spedding was elected to the National Academy of Sciences in 1952, before the main impact of the very effective ion-exchange separation of the rare-earth elements was felt. He also became the first to bear the title Distinguished Professor of Sciences and Humanities at Iowa State, in 1957. Among his 50-plus honors and awards was the William H. Nichols Award of the New York section of the American Chemical Society in 1952; the James Douglas Gold Medal from the American Institute of Mining, Metallurgical, and Petroleum Engineers in 1961 for achievements in nonferrous metallurgy; and the Francis J. Clamer Award from the Franklin Institute in 1969 for achievements in metallurgy. He was awarded an honorary LL.D. by Drake University in 1946, D.Sc degrees from the University of Michigan in 1949 and Case Institute of Technology in 1956, and an honorary membership in Verein Osterreichischer Chemiker in 1958.

Frank Spedding's major scientific and leadership roles have been many, the most noteworthy being the process development and production of large amounts of high-purity uranium and thorium during and after World War II, the discovery and development of the first workable separations of the rare-earth elements, and their reduction to high-purity metals. This was accompanied by a deep lifelong involvement in research that led to 260 publications. His crowning accomplishment in many eyes was the establishment of the Ames Laboratory, a national laboratory now supported by the U. S. Department of Energy, at a present level of $25 million per year for relevant research in chemistry, physics, metallurgy, materials sciences, environmental sciences, engineering, and mathematics. The breadth of Spedding's work was large; although his coworkers were many, the inspiration and drive to do the work originated largely with Spedding's perception of what needed to be done, how it should be done, and when it should be accomplished.

Frank Spedding retired as an active academician in 1972 at the age of 70 as emeritus professor of chemistry, physics, and metallurgy. For several years he carried on research with postdoctoral students and full-time scientists. He co-authored an additional 60 or so publications during this time. In the beginning he was in his office almost every day, but finally his energies began to fail. His last scientific publications came out in 1982. Early in the fall of 1984 he suffered a stroke that was to end his life on December 15, 1984. His remains are interred in the Iowa State University cemetery, along with those of his wife Ethel, who died in October 1996.

I HAVE DEPENDED A great deal on other sources for the information in this memoir. First are two public documents[2,3] and, most especially, an earlier summary of Spedding's career written by Professor Harry J. Svec and published in 1988 in the leading serial series on the rare earths.[4] Second are the former graduate students and colleagues of Spedding, who furnished many of the more personal experiences with and insights into the man: Adrian Daane, Jim Dye, Jack Powell, Bernie Gerstein, Earl Wheelwright, Joe Rard, John Croat, and Karl Gschneidner.

NOTES

1. G. N. Lewis and F. H. Spedding. A spectroscopic search for ^{3}H in concentrated ^{2}H. *Phys. Rev.* 43(1933):964.

2. History of the Ames Project under the Manhattan District to December 31, 1946 (E. I. Fulmer), Report ISC-10, December 9, 1947. Springfield, Va.: National Technical Information Service.

3. Ames Laboratory. A History of Innovation. Undated. Available at <http://www.external.ameslab.gov/Overview/ALhistory.pdf>.

4. H. J. Svec. Frank Harold Spedding. In *Handbook on the Physics and Chemistry of the Rare Earths*, vol. 11, eds. K. A. Gschneidner, Jr., and L. Eyring, p. 1. New York: Elsevier Science Publishers, 1988.

SELECTED BIBLIOGRAPHY

1929

With S. Freed. Line absorption spectra of solids at low temperatures in the visible and ultraviolet regions of the spectrum. *Phys. Rev.* 35:945-53.

1931

Interpretation of the spectra of rare earth crystals. *Phys. Rev.* 37:777-79.

1937

With H. A. Bethe. The absorption spectrum of $Tm_2(SO_4)_3 \cdot 8H_2O$. *Phys. Rev.* 52:454-55.

1947

With A. F. Voigt, E. M. Gladrow, and N. R. Sleight. The separation of rare earths by ion exchange. I. Cerium and yttrium. *J. Am. Chem. Soc.* 69:2777-81.

1951

With E. I. Fulmer, J. E. Powell, T. A. Butler, and I. S. Yaffe. The separation of rare earths by ion-exchange. VI. Conditions for effecting separations with nalcite HCR and one-tenth per cent citric acid-ammonium citrate solutions. *J. Am. Chem. Soc.* 73:4840-47.

With D. H. Parkinson and F. E. Simon. The atomic heats of the rare earth elements. *Proc. R. Soc. Lond.* 207:137-55.

1952

With P. E. Porter and J. M. Wright. Activity coefficient of rare earth chlorides in aqueous solutions at 25°C. *J. Am. Chem. Soc.* 74:2781-83.

With A. H. Daane. The preparation of rare earth metals. *J. Am. Chem. Soc.* 74:2783-85.

1953

With A. H. Daane and D. H. Dennison. The preparation of samarium and ytterbium metals. *J. Am. Chem. Soc.* 75:2272.

With C. J. Kevane and S. Legvold. The Hall effect in yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium, dysprosium, and erbium. *Phys. Rev.* 91:1372-79.

With S. Legvold, F. Barson, and J. Elliott. Some magnetic and electrical properties of gadolinium, dysprosium, and erbium metals. *Rev. Mod. Phys.* 25:129-30.

1954

With J. E. Powell and E. J. Wheelwright. The separation of adjacent rare earths with ethylenediaminetetra-acetric acid. *J. Am. Chem. Soc.* 76:612-13.

With J. Dye. Conductances, transference numbers and activity coefficients of aqueous solutions of some rare earth chlorides at 25°C. *J. Am. Chem. Soc.* 76:879-81.

With M. Griffel and R. Skochdopole. The heat capacity of gadolinium from 15°K to 355°K. *Phys. Rev.* 93:657-61.

With J. E. Powell. A practical separation of yttrium group rare earths from gadolinite by ion-exchange. *Chem. Eng. Prog.* 50:7-15.

With J. E. Powell and E. Wheelwright. The use of copper as the retaining ion in the elution of rare earths with ammonium ethylenediaminetetraacetate solutions. *J. Am. Chem. Soc.* 76:2557.

1958

With J. J. Hanak and A. H. Daane. The preparation and properties of europium. *Trans. Met. Soc. A. I. M. E.* 212:379-83.

1959

With G. Atkinson. Properties of rare-earth salts in electrolytic solutions. In *The Structure of Electrolytic Solutions*, ed. W. J. Hamer, p. 319-39. New York: John Wiley & Sons.

With J. E. Powell. The separation of rare earths by ion exchange. *Trans. Mel. Soc. A. I. M. E.* 215:457-63.

1960

With A. H. Daane. The rare-earth metals. *Met. Rev.* 5:297-48.

1961

With D. B. James and J. E. Powell. Cation-exchange elution sequences. I. Divalent and rare-earth cations with EDTA, HEDTA and citrate. *J. Inorg. Nucl. Chem.* 19:133-41.

1962

With R. M. Valletta and A. H. Daane. Some rare-earth alloy systems. I. La-Gd, La-Y, Gd-Y. *Am. Soc. Met.Trans. Q.* 55:483-91.

1965

With T. Murao and R. H. Good, Jr. Theory of Zeeman effect for rare-earth ions in crystal field with C_{3h} symmetry. *J. Chem. Phys.* 42:993-1011.

1970

With T. O. Brun, S. K. Sinha, N. Wakabayashi, G. H. Lander, and L. R. Edwards. Temperature dependence of the periodicity of the magnetic structure of thulium metals. *Phys. Rev. B* 1:1251-53.

1973

With J. J. Croat. Magnetic properties of high purity scandium and the effect of impurities on these properties. *J. Chem. Phys.* 58:5514-26.