Leo Brewer

1919–2005

BIOGRAPHICAL *Memoirs*

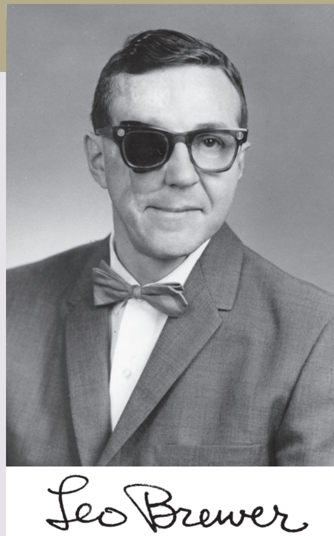
A Biographical Memoir by
Gabor A. Somorjai

NATIONAL ACADEMY OF SCIENCES

LEO **BREWER**

July 13, 1919–February 22, 2005

Elected to the NAS, 1959



By Gabor A. Somorjai

Leo Brewer was born in St. Louis, MO, where his father worked as a shoe repairman. From this humble beginning he went on to be one of the world's foremost scientists in the field of high-temperature chemistry. He was an important contributor to the Manhattan Project, the atomic-bomb effort that helped end World War II, but years later that assignment nearly cost him his life.

The Brewer family lived in Youngstown, OH, from 1919 to 1929, when, like so many others during the Great Depression, they moved west, settling in Los Angeles. Six years later, Leo enrolled at the California Institute of Technology (Caltech). As an undergraduate, he was strongly influenced by chemistry professors E. Swift and D. Yost and had his first taste of research studying equilibria and kinetics of olefin hydration under D. Pressman and H. J. Lucas. Upon receiving his B.S. in 1940, Brewer was encouraged to pursue higher education by Linus Pauling. He enrolled at the University of California, Berkeley, where he continued his studies of kinetics under Axel Olson. In 1942, shortly after the United States's entry into WW II, Brewer completed his doctorate—after a mere 28 months. His dissertation was on the effect of electrolytes on the kinetics of aqueous reactions.

After Brewer obtained his Ph.D., Wendell Latimer, a professor of chemistry at UC Berkeley, recruited him to join the newly formed top-secret wartime research group that came to be known as the Manhattan Engineering District Project, or simply the Manhattan Project. Brewer was assigned to work under Ermon Eastman (whose deteriorating health forced him to withdraw from the project soon after it began) and Latimer. Brewer headed a group, composed of Leroy Bromley, Paul Gilles, and Norman Lofgren, assigned the task of identifying the possible high-temperature properties of the newly discovered element plutonium, then available only in trace amounts.

The first challenge, of course, was how to handle this metal at high temperatures. Because no pertinent data existed for plutonium, the group was forced to use theoretical models based on the limited data for similar elements. In their studies of the sulfides of cerium, thorium, and uranium, they investigated various refractory materials. One prominent result was a new material, cerium sulfide (CeS), which they called impervium," and of which they made several hundred crucibles for use at Los Alamos National Laboratory. This work initiated Brewer's 60-year-long devotion to developing models for predicting the properties of materials.

In 1943, Brewer began his association with Lawrence Radiation Laboratory (later the Lawrence Berkeley National Laboratory), which lasted until 1994. In 1945, he married Rose Sturgo (who died in 1989), with whom he had three children: Beth, Roger, and Gail. In 1946, with his war work behind him, Brewer was appointed assistant professor in the Department of Chemistry at UC Berkeley. Brewer's dual appointment afforded him the opportunity to take an active role in all levels of academic education, both inside and outside the laboratory. Besides providing classroom instruction in solid-state chemistry, heterogeneous equilibria, and inorganic chemistry, Brewer delivered lectures and supervised laboratory work for laboratory courses in freshman chemistry, advanced quantitative analysis, instrumental analysis, inorganic synthesis, inorganic reactions, and organic chemistry, as well as courses in chemical thermodynamics that ranged from the sophomore to graduate level. To help ensure a high standard of instruction throughout the curriculum, Brewer initiated a course for the department's teaching assistants of freshman chemistry.

In 1950, after becoming associate professor, Brewer formed an interdepartmental spectroscopy seminar with professors F. A. Jenkins (physics) and J. Phillips (astronomy). Known as a caring and gifted teacher, greatly admired by students and colleagues alike, Brewer was awarded the Leo Hendrik Baekeland Award from the American Chemical Society in 1953. This award is given every two years to an American chemist under the age of 40 for "initiative, creativeness, leadership, and perseverance."

William Hicks, one of Brewer's graduate students, recalls working under Brewer in the 1950s:

> *I first met Professor Brewer when I took Thermodynamics 114 from him in my first year of graduate school at UC Berkeley in 1953. I was aware that Professor Brewer had played an important part in the creation of*

atomic weaponry near the end of World War II. I believe he searched for container materials that would hold reactants at high temperatures when developing these processes. I took the class in a room on the first floor of Gilman Hall. I remember that he taught the course in an informal way—which I appreciated—using practical applications of thermodynamics to reactions at high temperatures, rather than [relying on] formal lectures.

By the next year I [had] joined his students Jim Kane and Oscar Krekorian in the south end of Gilman Hall on the second floor. Professor Brewer shared his office and adjoining rooms with his students and worked closely with us. I, like several of his students, did my experiments at high temperatures, [such as] 3000 degrees C, in a King furnace located in the Physics Department Building across the courtyard from Gilman Hall. In this furnace, high temperatures were attained by passing electric current through a hollow carbon tube, which was kept in a high vacuum. We studied high-temperature species by observing the light from the furnace with a spectroscope as we varied the temperature of the carbon tube.

Brewer achieved the rank of full professor in 1955. He served as a faculty member of the Department of Chemistry at UC Berkeley for over 60 years, during which time he directed 41 Ph.D. candidates and nearly two dozen postdoctoral research associates. Brewer published nearly 200 articles and, with chemistry professor Kenneth Pitzer, revised Gilbert N. Lewis and Merle Randall's classic 1923 text, *Thermodynamics and the Free Energy of Chemical Substances*. Of his research, colleague and former Berkeley vice chancellor Robert E. Connick (1928–2014) said, "It is probably fair to say that he has contributed significantly to our understanding of the chemistry of almost every element of the periodic table.…He created the field of modern high-temperature chemistry." In 1959, Brewer was elected to the National Academy of Sciences.

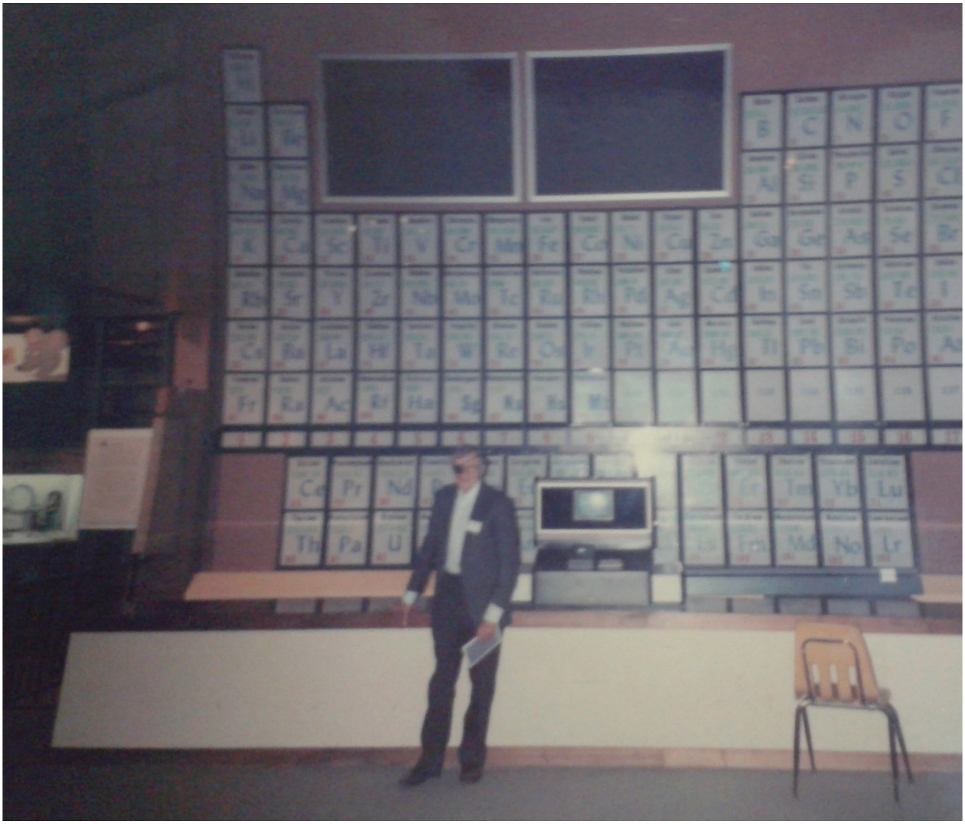
One of Brewer's first published papers was on the heat of the sublimation of graphite to carbon atoms. This work, detailed in the doctoral thesis of Paul Gilles, involved measuring the vapor pressure of graphite near 3,000 degrees K. Linus Pauling had used 125 kcal as the value for this heat of sublimation to establish his widely quoted carbon-bond energies. But Brewer showed that Pauling had chosen a value, based on spectroscopic data for the dissociation of CO, that was much too low. The CO data gave three possible values—125, 141 and 170 kcal—and only the highest would be consistent with Brewer's results. One day Pauling came to Berkeley to discuss this problem. We assume that Pauling did not want to change his bond energy values, and indeed, he did not agree to switch to the 170 kcal value. However, later experiments confirming Brewer's work finally convinced Pauling to change to a value close to 170 kcal. This is just one of the cases where Brewer stuck to his experimental results despite strong opposition.

Brewer's early high-temperature work also showed that the equilibrium vapor above CuCl consisted mainly of Cu_3Cl_3 molecules at normal pressures. This simple observation led to what became known as Brewer's Rule. He showed that when vapor and condensed phases are in equilibrium, the vapor species become more complex as the temperature is raised. This phenomenon includes the formation of polymers and unusual oxidation states. His rule became the foundation of the field of high-temperature chemistry.

Although Brewer's research covered an unusually wide range of subjects and employed a multitude of techniques from theory to spectroscopy, his primary interests were in high-temperature thermodynamics, materials science (including refractory containment materials), metallic phases, and metallic bonding theory (which incorporated the concepts of electron promotion and generalized acid-base theory). Though fundamental in nature, his research had its practical applications as well, from nuclear reactors to space sciences, including the development of a corrosion-resistant stainless steel based on chemical reactions he described. He was much sought after as a consultant.

A great deal of Brewer's research involved the resolution of discrepancies between reported experimental values and values predicted by chemical bonding models. In many instances, the reported data were shown to be in error, and the reliability of the model was confirmed. Examples are his demonstrations that the enthalpies of formation of C(g) and N(g) were much larger than the widely accepted values. Brewer's compilation of the thermodynamic properties and phase diagrams of 101 binary systems of molybdenum also provides many examples of the use of predictive models when no reliable experimental data are available.

In some instances, the experimental results were confirmed and it was necessary to improve the models. An example is the wartime study that uncovered evidence of polymerization in high-temperature vapors, which led to a general theory that predicted that saturated high-temperature vapors would be complex mixtures of species and that the complexity would increase with increasing temperature. These predictions have been confirmed by high-temperature researchers for many systems. Refractory studies initiated with the sulfides were extended to studies of silicides, borides, and other refractory phases. The experience of the Manhattan Project on the use of platinum to reduce the



Leo Brewer in UCB. (Courtesy Hui-Fen Wu.)

volatility of lanthanides and actinides was extended to a wide range of transition-metal intermetallic compounds through use of the Engel correlation of electronic and crystal structures. These extensions led to the prediction of the structures and compositions of the phases of most of the two billion multi-component phase diagrams of the transition metals.

Brewer devoted major effort to the characterization of the thermodynamic properties at high temperatures, with the result that the critical evaluations of the thermodynamic properties from the Manhattan Project were periodically updated. One of his compilations addressed the solid, liquid, and gaseous phases of the elements and their oxides between room temperature and temperature to above 3,000 degrees K. The thermodynamic applications of these data were well illustrated in the 2nd edition of Lewis and Randall's *Thermodynamics*, which Brewer and Pitzer revised in 1961. Brewer's global interest in all of the elements is illustrated by a paper in 1951 on their equilibrium distribution in Earth's gravitational field.

Brewer conducted a wide range of spectroscopic studies both at high temperatures and in matrices to fix the thermodynamic properties of high-temperature vapors. From 1950 to 1970, he published numerous papers that analyzed the spectra produced by high-temperature gaseous molecules; several of these papers described a molecular-beam method for determining the gaseous molecules' ground electronic states. After George Pimentel at UC Berkeley developed low-temperature matrix isolation, Brewer produced many papers on the spectra of his high-temperature molecules in a frozen inert matrix. Brewer also had a long-term interest in the electronic states of I_2, and he published several papers on its remarkable complexities.

Much of Brewer's later research was aimed at characterizing the extremely strong generalized Lewis acid-base interactions between the platinum group metals and the lanthanides, actinides, and left-hand transition metals. A combination of high-temperature solid electrolyte cells, equilibration with oxides, carbides, and nitrides, and vapor pressure measurements was used. These intermetallics were shown to be among the most stable of all types of compounds, as predicted by the Engel theory.

Niels Engel was a Danish scientist who Brewer met during Engel's sabbatical visit to Berkeley in the late 1940s. Engel had suggested a correlation between the number of conduction electrons and the crystal structure of the metals. Brewer extended this concept to include the nature of d and f electrons and the concept of acid-base interactions. Starting investigations with undergraduate students, he tested these ideas by heating zirconium chloride (ZrC) with the noble metal platinum, and he found that the formation of $ZrPt_3$ released a great deal of energy despite the inherent stability of ZrC. Over several years Brewer developed the Brewer-Engel theory for such bonds, and he published many papers about its applications.

In addition to his teaching, Brewer served on many committees. At the end of World War II, he helped form the Association of Northern California Atomic Scientists. He was instrumental in founding the National Research Council's Committee on High-

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Temperature Chemistry, and he organized the first Gordon Research Conference on High-Temperature Chemistry. At the request of the Atomic Energy Commission and its successors—the Energy Research and Development Administration and the Department of Energy—Brewer served on the DOE Council for Materials Sciences and the DOE Selection Committee for the Fermi Award. He maintained close ties with organizations that represented the international scientific community, including the International Union of Pure and Applied Chemistry and the International Atomic Energy Agency.

In 1960, Brewer's war work caught up with him: he developed cancer as a result of his experiments with beryllium while working on the Manhattan Project. He had radical surgery to remove his right eye and part of his face, which saved his life. He credited Kenneth Pitzer for his survival: "When all the doctors had written me off, Ken didn't believe it. He knew there were other methods, and referred me to a colleague who knew of an alternative. Then Ken urged me to go have the surgery, and it worked. I owe my life to him."

Remarkably, Brewer's health problems didn't affect his productivity. In 1961, he was appointed director of the Inorganic Materials Research Division of Lawrence Berkeley National Laboratory, a post he held until 1975. In 1966, he was selected by the Academic Senate at UC Berkeley to deliver the annual Faculty Research Lecture, titled "A Broad University Education Leads to Astrochemistry."

In addition to his scientific work, Brewer had an avid interest in California flora, cultivating a native garden around his home and visiting native plant sites throughout the state. In 1965, he became one of the founding members of the California Native Plant Society, and later a species of manzanita was named after him—*Arctostaphylos uva-ursi leo-breweri*, also referred to as "Leo Brewer's Manzanita"—to honor his contribution to the study and preservation of California flora.

Brewer was a very popular teacher who took great interest in his students' work. Just before he retired in 1988, he received the Henry B. Linford Award for Distinguished Teaching from the Electrochemical Society in recognition of his achievements as an educator. Gabor Somorjai, a chemistry professor at UC Berkeley who first arrived there as a first-year graduate student in 1957 after escaping from Hungary, recalls:

> *It was my first semester at Berkeley, and I had to make the choice [whether] to pursue organic chemistry or chemical engineering. Leo Brewer taught a course in Thermodynamics to first-year grad students. He was absolutely marvelous. Not only was he exceedingly knowledgeable, his enthusiasm lit up the subject. After taking this course, I had absolutely no doubt that I wanted to become a physical chemist. His teaching had a profound influence on me.*

Another one of Brewer's former graduate students, John Gibson, shared these memories of working with him:

> *As a Ph.D. student under the supervision of Leo Brewer during 1979–1983 I have many memories of Leo, remarkably all of them fond. It was not until I entered my postgraduate career that I fully appreciated what a superb person and adviser Leo was. While a graduate student, I took Leo's generous, gentle, and effective mentorship for granted. Among my many reminiscences of Leo, I will recount only a couple that reflect his wonderful character.*
>
> *In addition to group meetings that were rather typical, except for the keg of sherry, Leo encouraged his undergraduate and graduate students to visit him in his office essentially whenever they had a hankering. I quite often took advantage of this opportunity, which was not an option with most graduate student advisers. Leo would patiently listen to my questions, which were generally inexcusably ignorant, and then proceed to gently and clearly convey his extraordinary insights.*
>
> *Quite more amazing to me than Leo's generosity of his time and comprehensions with his own students was his goodwill toward the students of others. Memorable instances included when I was informally meeting with Leo and an undergraduate from a course not being taught by Leo would appear unannounced at his office; the student would be there to request clarification on some issue that the course instructor did not have the time or patience to address. I would move aside to make room at Leo's desk for the welcome visitor for however long it took Leo to*

good-naturedly and clearly provide the needed insights, which invariably also provided me with new understanding. Leo's reputation as an extraordinarily caring and giving teacher was known to the community of Berkeley chemistry students, and many of them benefited from his generosity.

One morning while I was toiling in the graduate student den in the dungeon of Latimer Hall, Leo strolled in, in his energetic manner of "strolling," and invited me to join him and a visitor. Upon entering Leo's office, I was delighted to find myself in the company of Linus Pauling; Leo and Linus were old friends, and Linus would occasionally stop by. I dared not ask my typical unenlightened questions of Linus, but only managed to mumble some inane words of admiration and my regret that I did not have my copy of The Nature of the Chemical Bond *for his signature. The three of us spent a marvelous (for me) hour while the two greats, Linus and Leo, chatted seemingly as would any other two very bright blokes. It was apparent that Leo knew that this would be an unforgettable experience for me when he invited me to participate in his reunion with Linus. This was typical of Leo's nature: when Linus appeared at his door [Leo] thought not merely of meeting with his pal, but also of providing a receptive young student with an unforgettable experience.*

Ara Chutjia writes:

I was a graduate student with Leo Brewer during the period of about 1964-1967. In that time I always felt a warm attraction to Leo. He offered valuable advice and encouragement when things weren't going well experimentally. He was good-natured, the type of person who would react to any setback with words like, "Oh, my, we'll just have to buy another power supply," or "Hmm, the shop can build another resonance lamp in a day or two."

The weekly group meetings were a valuable touchstone for presenting new ideas, and having one's science judgement and approach critically evaluated. If Leo didn't answer a question immediately, he could always pull it out in a minute from the 24th publication in the 11th vertical pile, atop one of his twelve file cabinets.

> *I visited him once after his retirement – about twenty years after my graduating Berkeley. We picked up immediately where we'd left off, and quickly moved up to what we were presently doing. I appreciated his wealth of patience, and abundance of knowledge in many quite-unrelated fields of research. I wish I had visited him more often.*

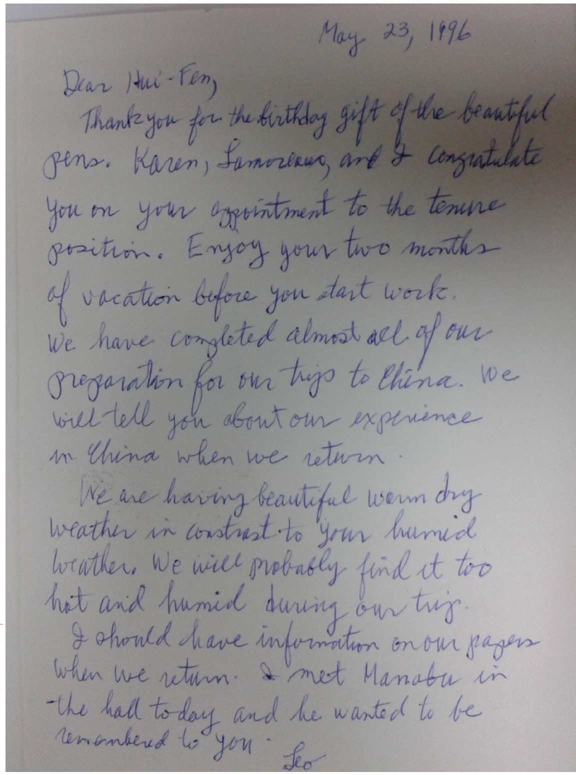
Former Brewer post-doc Hui-Fen Wu recalls Brewer as

> *...a good learner, good friend, good teacher, good researcher, good organizer, and good team leader. He inspired and influenced every one of the many lab members and students that he instructed.*
>
> *As a post-doc working with Prof. Brewer, I worked on many projects leading to the publication of four papers. I was given freedom, respect and the time to develop skills and knowledge in the material science field, which was a totally new field to me; my training was only in the field of mass spectrometry.*
>
> *I learned from Brewer to enjoy my research work. We used to happily work in the Lab 7 days a week because we did not think of research as "work." For us it was play and we had fun with the research.*

Handmade card from Brewer to Hui-Fen Wu, December 1995. (Courtesy Hui-Fen Wu.)

Upon Leo's official retirement from UC Berkeley in 1989, an academic symposium was held in his honor and he was presented with the Berkeley Citation. Unfortunately, he was unable to share his retirement with his wife Rose, who died that same year. In 1998,

Handmade card from Brewer to Hui-Fen Wu, May, 1996. (Courtesy Hui-Fen Wu.)



May 23, 1996

Dear Hui-Fen,

Thank you for the birthday gift of the beautiful pens. Karen, Lamoreaux, and I congratulate you on your appointment to the tenure position. Enjoy your two months of vacation before you start work.

We have completed almost all of our preparation for our trip to China. We will tell you about our experience in China when we return.

We are having beautiful warm dry weather in contrast to your humid weather. We will probably find it too hot and humid during our trip.

I should have information on our papers when we return. I met Manabu in the hall today and he wanted to be remembered to you.

Leo

Note on reverse of card above. (Courtesy Hui-Fen Wu.)

the American Association of University Professors recognized Leo for his 50 years of "meritorious support of the principles of academic freedom and tenure."

In 2000, Leo was invited to present the plenary lecture at a conference on Plutonium Futures at Los Alamos National Laboratory; and in 2001, he was honored for his 50 years of membership in the Royal Society of Chemistry.

Leo Brewer passed away on February 22, 2005, at Deer Hill Care Home in Lafayette, CA. He was 85 years old, and survived by his three children and six grandchildren.

Michael J. Cima, a professor in the Department of Materials Science and Engineering at MIT, recalls:

> *There are many anecdotes from my time working with Leo. The one I think of most often is a conversation I had with him in his office. I had stopped by to get his comments on some experimental results. Our conversation eventually turned to my asking for advice. I felt that I was soon to make some decisions on my future career. I asked what he thought about some possible directions. He replied with a laugh and said, "Whenever I wonder what direction to go, I look up at this mobile." The mobile hanging in his office consisted of many hands, all pointing in different directions. "It's good to have options."*

Service to Professional Publications

Brewer sat on the editorial advisory boards of many respected scholarly journals and academic monograph series, including:

The Journal of Physical Chemistry Solids (1956–1992),
Progress in Organic Chemistry (1958–1969),
Journal of Chemistry Physics (associate editor, 1959–1963),
Progress in Inorganic Chemistry (1967–2005),
Progress in Solid State Chemistry (1967–1996),
High Temperature Science (founder, 1968–2005),
The Journal of Chemistry Thermodynamics (1969–1978),
The Journal of Solid State Chemistry (1969–1984),
The Journal of the Electrochemical Society (divisional editor, 1976–1984),
The Journal of Chemical Engineering Data (1978–1981),
The Journal of Physical Chemistry Ref. Data (1989–1992),
The Metals Handbook (coeditor, 1983),
The Princeton Series in the Physico-Chemical Sciences for Technology (coeditor, 1983–2005),
and *The Handbook of Chemistry and Physics* (1991).

In addition, Brewer single-handedly compiled and maintained Part II of the *Bibliography on the High-Temperature Chemistry and Physics of Materials* and authored nearly 200 articles on a variety of advanced topics in the field of thermodynamics.

Awards

Brewer's professional achievements were recognized with many awards and honors, including the L. H. Baekeland Award of the American Chemical Society (1953), the E. O. Lawrence Award of the Atomic Energy Commission (1961), the Palladium Medal (1971) and the Henry B. Linford Award for Distinguished Teaching (1988) of the Electrochemical Society, and the William Hume-Rothery Award of the Metallurgical Society from the American Institute of Mining (1983).

Brewer also served as a Guggenheim Fellow (1950) and as a member of the National Academy of Sciences (elected 1959), the American Academy of Arts and Sciences (1979), and the American Society for Metals. In 1984, a special *festschrift* in his honor was prepared by his former students and colleagues and published under the title *Modern High Temperature Science*.

SOURCES FOR THIS MEMOIR

Jane Scheiber, Rollie J. Myers, Gerd M. Rosenblatt, Herbert L. Strauss, Wikipedia page for Leo Brewer (partially adapted from his autobiographical essay), and biographical essays prepared by his colleagues and students, including Paul Gilles, Karen Kruschwitz, Richard M. Brewer, Michael J. Cima, John K. Gibson, Gabor Somorjai, and William Hicks.

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