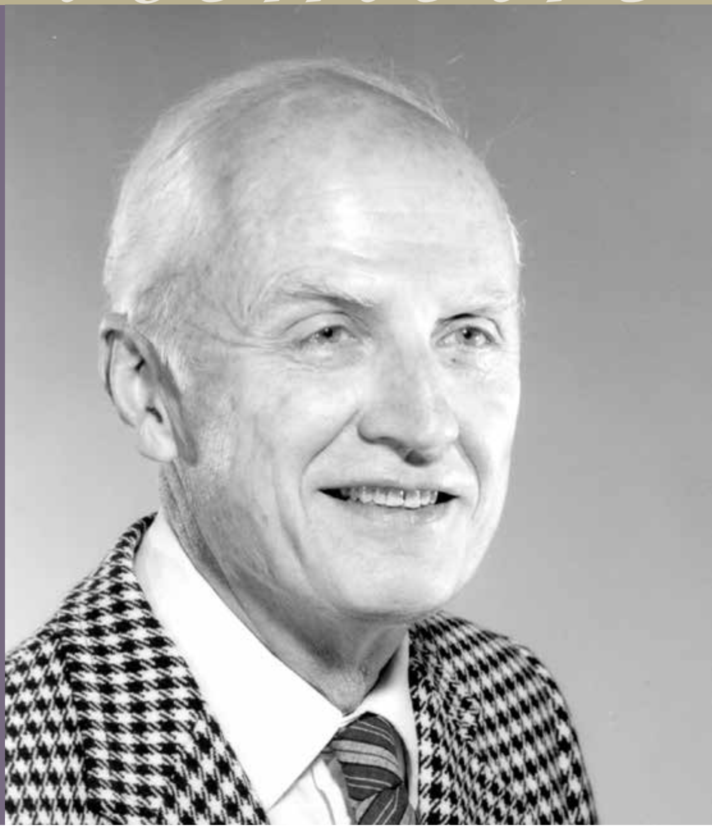
Harold S. Johnston

1920–2012

BIOGRAPHICAL *Memoirs*



A Biographical Memoir by
Gabor A. Somorjai

NATIONAL ACADEMY OF SCIENCES

HAROLD SIDDLE **JOHNSTON**

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Elected to the NAS, 1965

By Gabor A. Somorjai

Harold S. Johnston, a pioneering atmospheric chemist, is best known for his landmark paper, published in *Science* in 1971, showing that nitrogen oxides emitted directly into the stratosphere by then-proposed supersonic transport aircraft might cause substantial depletion of the Earth's ozone layer. The importance of this paper was not so much its effect on plans for supersonic transport aircraft, which were slight, but, rather, that it made the first powerful case that human activities could have a significant environmental impact on global atmospheric ozone. The extraordinary insights he presented in this paper, as well as his efforts to communicate the results to the public and policymakers, led to a transformation in the state of stratospheric science and spurred the initial development of modern programs of stratospheric observation and modeling.

Johnston, born in rural Georgia in 1920, earned a bachelor's degree in chemistry from Emory University in 1941 and a Ph.D. from Caltech in 1948—his quest for his doctorate having been interrupted by three years of secret volunteer war work for the army. After doing research and teaching chemistry at Stanford for ten years beginning in 1947, he spent a year on the Caltech faculty, then moved on to UC-Berkeley, where he taught until his retirement, except for the period from 1966 to 1977, when he served as dean of Berkeley's College of Chemistry.

One of the most exceptional atmospheric chemists of the twentieth century, Harold S. "Hal" Johnston was born in the town of Woodstock, Cherokee County, Georgia, on October 11, 1920. Woodstock was a cotton-farming community with a population of fewer than 500, lacking paved roads or electricity until the late 1930s. A true son of these rural roots, Hal Johnston nevertheless came to perform groundbreaking work on atmospheric kinetics, in both laboratory and theoretical studies, that greatly advanced understanding of the processes affecting ozone in the troposphere and stratosphere, especially related to the chemistry and impacts resulting from civilization's nitrogen oxide (NOx) emissions.

North Georgia was populated by people of the Cherokee Nation until they were driven out in the 1830s and forced to trek to the unorganized territory that later became Oklahoma on the long and lethal journey known as The Trail of Tears. Following their expulsion the land was surveyed and given away by lottery in 40- and 200-acre lots to white settlers. Hal's maternal great-great-grandfather, Joseph Stallworth Dial, born in 1793 in South Carolina, moved to Cherokee County and bought up lots that the first white settlers had put up for sale or abandoned, eventually accumulating some 2,000 acres. Hal's great-grandfather Dial was a dashing cavalry officer who inherited half his father's land. Unfortunately, later in life he became an alcoholic, losing his land and ending up living in a small house in Woodstock that his son, Hal's father, bought for him.

Hal's paternal great-grandfather, bearing the unusual name Doctor Medicine Johnston, was impoverished by the Civil War and died in 1869. His son, Hal's grandfather, Doctor Medicine Johnston, Jr., had to care for his mother and sister from age 14, working as a farm laborer and gold miner in North Georgia. He borrowed $100 to buy a small farm adjacent to the family's own small farm, in time repaid the debt, and slowly increased his holdings to 300 acres. Disliking his birth name, when he opened a general store in Woodstock he called it the J H Johnston Co. Over the years, in addition to the store, he became a prosperous local businessman and patriarch. He boasted that he had gone to school only six months in his life and regarded college "a waste of time and spoiler of the young." He built himself a large brick house in town, with gleaming white columns on the front porch and heavily used brass spittoons in the living room.

Hal's father, Smith Lemon Johnston, wanted to go to college to become a Methodist minister, but his father forced him to work in the family business instead. Smith Johnston eventually managed to pay his own way for one year at Young Harris College but then gave in and joined the family businesses, becoming a partner in the J H Johnston Co. and the Bank of Woodstock. However, he remained active as a lay member of the Methodist Church. Hal's mother, Florine, was also scholarly by nature but had very little chance to pursue her interests. Hal's father and mother resolved that their children would receive college educations, and despite the privations of the Depression they were good to their word. In addition to Hal, Smith and Florine had three other sons; Smith Jr., William, and Richard. All four boys went on to complete college degrees.

Hal grew up on his father's one-acre farm, which included "a garden, chickens, cow barn, pig pen, and flies."

At the age of 13 Hal became severely ill with rheumatic fever, which affected his heart. His uncle, a doctor, advised his father not to "waste money sending him to college, since he won't live long enough to get any good out of it." Contrary to expectations, although never able to run, swim, or engage in sports, Hal survived. "I found out that the average survival time was about 15 years," he said in an oral history project of his life conducted in 1999 by the University of California-Berkeley. "I've had a moving 10-year life expectancy; almost every decade, I have understood that I probably wouldn't last till the next one."

Education and employment

In 1937 Hal entered Emory University. After reading Hitler's *Mein Kampf* in a history class, he changed his major from English to chemistry, which he felt would be of more use during what he saw as the impending war. "Knowing I would be exempt from the draft, I didn't want to be left out," he explained. Johnson graduated in 1941 with an A.B. degree in chemistry and a minor in English literature.

In September of that year Hal entered the California Institute of Technology (Caltech) as a graduate student and, as he later said, "luxuriated in the fact that nerds were normal there." After two semesters, however, he suspended his studies to join a secret war project involving laboratory work at Caltech on defense against "possible new war gases"—that is, chemical weapons. Johnston worked as a "meteorologist with the U.S. Army Chemical Warfare Service as they carried out field research with active chemical weapons near Bushnell, Florida. In 1945 he returned to Caltech to finish his doctoral degree.

Hal received his Ph.D. in chemistry and physics in 1948. That same year he married Mary Ella Stay of Cleveland, Ohio, who had graduated from Mount Holyoke College in Massachusetts. Hal conducted research and taught chemistry at Stanford University from 1947 to 1956 and at Caltech in 1956-'57. He then joined the University of California, Berkeley, as a professor of chemistry and remained there for the rest of his career. He served as the dean of Berkeley's College of Chemistry from 1966 to 1977 and continued to teach until his retirement in 1991, when he became professor emeritus. Hal mentored more than 40 Ph.D. students and many undergraduates. Many of his former students have continued his legacy in making substantial contributions to the study of atmospheric chemistry. But he also influenced many others besides his Ph.D. candidates. For example, Bob Charlson, well known for his studies of atmospheric particles and now a professor emeritus of the University of Washington, took freshman chemistry from Hal and still treasures the glass-blowing goggles that Hal gave him when he successfully made a T joint. His work with Hal as an undergraduate led to his career in atmospheric science. Hal also influenced two other highly regarded chemists: Professor (now emeritus) and Nobel Chemistry Laureate Dudley Herschbach of Harvard, an undergraduate with Hal, and Susan Solomon of MIT (National Medal of Science), who did graduate study under Hal and Paul Crutzen and who went on to be arguably Hal's most successful graduate student as the first scientist to provide a correct explanation of the Antarctic ozone hole. Herschbach fondly remembers starting his career as a university freshman by meeting Hal, whom he referred to as being intense, earnest, and wonderfully stimulating. Herschbach worked in Hal's lab at Stanford and described him as one of his most important influences. Herschbach's Nobel autobiography states, "My chief mentor at Stanford was Harold Johnston, who imbued me with his passion for chemical kinetics." Hal's pioneering research in atmospheric chemistry and kinetics had a crucial impact on Herschbach, who shared his Nobel Prize with John Polanyi and Berkeley chemist Y. T. Lee. "Lots of people weren't prepared to believe what he showed," recalled Herschbach. "He was really one of the great pioneers in stratospheric chemistry and had a very major impact on everyone who went into the field. It was really him that inspired and intrigued me about trying to understand what happens at the molecular level in chemical reactions," Herschbach said. "Hal was my adviser all the way through college, and he's my most important mentor in becoming a scientist."

Hal Johnston at lunch with Tom Paukert and John Birks at the Johnston Ranch, July 1969. (Photo courtesy Leo Zafonte.)

John Birks, one of Hal's graduate students, remembers:

> *I joined Hal Johnston's group in the fall of 1968. This was a time of political unrest, especially at Berkeley and a few other college campuses because of the ongoing and escalating Vietnam War. It was during the months following the "Summer of Love" in San Francisco when thousands*

of young people, the leading edge of the baby boomers, descended on the Bay Area. At that time Hal Johnston was serving as Dean of the College of Chemistry. Most of his research group was doing research on the kinetics and photochemistry of air pollution. Nearly all of the projects involved some aspect of "molecular modulation," a technique he had invented earlier for extracting quantitative kinetics and spectroscopic information using the phase shift technique. At the time I thought air pollution chemistry was too complicated, and I wanted to work on something simpler and more fundamental from a physical chemistry point of view. Ironically, because of my association with Hal Johnston, I ended up spending my entire career working in the area of atmospheric chemistry anyway and ultimately found the complexity of air chemistry fascinating.

At one point, I asked Professor Johnston about why he became a Dean. He told me that it was not a job he really wanted to do, but that he did it out of obligation to the department simply because he was asked to do it. He had a very strong sense of departmental citizenship. It was a tough time to be Dean. There were student protests with an attempt to shut down the campus. I had a sense that Hal agreed with the motives of the students but believed that it would be wrong to shut down the very institution that provided freedom of thought and speech and would just play into the hands of the right-wing politicians such as Ronald Reagan, who was Governor of California at the time. Being part of the administration, Hal was not publicly vocal on this issue. But George Pimentel was one of the speakers at an event held in the Greek Theatre where he expressed what was probably Hal's position—that we should oppose the Vietnam War but not shut down the university where there was freedom to debate such important issues.

Almost exactly one year before my return to Berkeley, Hal published his famous paper on the effects of SST aircraft on stratospheric ozone (Reduction of Stratospheric Ozone by Nitrogen Oxide Catalysts from Supersonic Transport Exhaust. Science *173:517-522, 1971). The details of how this paper came about are discussed in Lydia Dodo and Harold Schiff's book,* The Ozone War*. Hal was attending a meeting in Boulder, Colorado (March 18-19, 1971), reviewing the potential effects on the stratosphere of building and deploying a large fleet of Boeing SST* *commercial aircraft. The presented results showed no significant effect of NOx on the ozone layer. At the meeting Hal did a "back of the envelope" calculation showing that there should be about 50 percent ozone depletion for the amount of NOx assumed to be emitted by the aircraft. There turned out to be an input error for a rate constant entered into the model by the presenter at that meeting. This was a turning point in Hal's career. From that time on, he completely devoted himself to stratospheric chemistry and to keeping the debate honest about the effects of SST aircraft on stratospheric ozone.*

A fellow graduate student, Leo Zafonte, remembers:

In 1968, Harold Johnston's laboratory was in the basement of Hildebrand Hall; it was filled from back to front with an assembly of graduate students and their apparatus, many working on the new molecular modulation technique which they developed. Some of the aisles/walkways were surprisingly narrow to me on my first walk through of the laboratory. This modulation technique was very new and actually extremely powerful for that time. Photochemistry was initiated by modulating a photochemical light source at a set of fixed low frequencies; this was the key to the many innovations that made the technique work. Standard spectroscopic detection techniques (IR, UV, and MS) were adapted and the detector output was processed by phase-locking the signal to the light modulation frequency. In this way, the experiment focused on the detection of species related in some way to the modulated light excitation. Both the signal intensity and phase shift from the photoexcitation were used to interpret the kinetics. For a while, I do not think that there was an empty nook or cranny in the laboratory that escaped having one of these systems.

Hal tended to let his graduate students work very much on their own so that they could develop their thesis topics with a high degree of independence. He gave his students both complete freedom and unflinching support for the decisions they made (but within the funding limits he was subject to). I was a beneficiary of this same support over the three years that I worked there. One day when I asked Hal why he did this, he simply responded that too many times in the past he would find

Earl Morris with Harold Johnston, 1970. (Photo courtesy Earl Morris.)

that his students were right and that he was wrong. I was deeply touched, not only by his words but also with the humility, the trust, and the sincerity by which he expressed them. It was this attitude that permeated the entire laboratory and ingratiated him to many. There was still a part of him, though, that longed to be fully involved in research, which he had to miss because of the demands of his tenure as Dean; yet he always found time in a busy schedule to listen to what his students were up to and to give them wise support out of his years of experience.

Hal was remembered fondly by another graduate student, Frank Magnotta:

Professor Johnston always went by Hal to us grad students. But that familiarity never meant that he was anything less than a leader, teacher, and mentor. His wealth of knowledge and patient manner always allowed the student to reap the benefits of pursuing his or her own interests and goals. The excitement and motivation that I acquired throughout the course of my graduate work was a direct reflection of Professor Johnston's constant concern for his students. He was always available to talk over problems and suggest avenues of approach, always insisting on working in parallel on problems, in case one particular direction did not work out.

My particular research topic involved measuring the photo-dissociation quantum yields and product branching ratios of the nitrate free radical. The results obtained were somewhat intriguing and not at all expected, which is always exciting (or disconcerting, depending on one's attitude) in research. Hal would say, "If you got the result you expected, what would you have learned?" Sensing he was not totally convinced of the *results, I repeated the experiment many times over and checked every variable to near exhaustion. We published the results along with a second short paper, which re-measured an atmospherically important reaction rate, a side result of the initial quantum yield work. The second paper was rejected, as it 'did not agree with the previously accepted value.' Of course, Professor Johnston was very concerned, and asked in his gentle manner, "Frank, are you absolutely sure of your result?" I replied, "Absolutely!" As it turned out, my new result was later shown to be correct. As for the quantum yield work, some 16 years later I got a phone call from Professor Johnston, who informed me that my experiment was just repeated by Professor Yuan T. Lee and his students, in a molecular beam, and totally confirmed my flow cell results. That put a big smile on my face and [I] am sure Professor Johnston was smiling too. Some 6 years following that call, I was invited to a Festschrift celebration party in his honor, at the Faculty Club on the Berkeley campus, where we reunited and talked over old times and wondered why we never resubmitted the reaction rate paper.*

Professor Johnston was an inspiration to me and to all of his students. I asked him once, "When do you know that I'm ready to write up my thesis?" and he replied, "When you start teaching me more than I am teaching you." I am forever grateful to Professor Johnston for guiding me through my graduate education and for not holding me to that one requirement.

Accomplishments

Hal built his career around the study of the fundamental kinetics of nitrogen oxides. He systematically examined and quantified the chemistry of all the key nitrogen gases, including their reactions with hydrogen and chlorine oxides. There is likely no other single individual who contributed as much to the understanding of the chemistry of molecules of such importance in the atmosphere. He paired his pioneering studies of specific reactions with work on the theory of elementary chemical reactions, which established cornerstones for modern reaction-rate theory. Many colleagues recall his textbook on reaction-rate theory as the classic they learned from.

Hal's work on atmospheric kinetics greatly advanced understanding of the processes affecting ozone in the troposphere and stratosphere, especially related to the chemistry and impacts resulting from nitrogen oxides. His 1971 paper in *Science* was important not only for its effect on the aircraft industry, but also because it made the case that human activities could have a significant environmental impact on global atmospheric ozone. At the time, very little was understood about stratospheric composition and associated chemistry. The possibility that catalytic reactions involving nitrogen oxides might be important to the natural destruction of stratospheric ozone had been published only the year before.

Hal's lab studies of nitrogen oxide chemistry led him to recognize that supersonic transport aircraft would produce NOx that would affect ozone. Using a model that was simple and transparent, he made a variety of estimates of the potential effects on the ozone layer from a fleet of such aircraft. The extraordinary insights presented in this paper, as well as his efforts to communicate the results to the public and policy makers, led to a transformation in the state of stratospheric science and spurred the initial development of modern programs of stratospheric observation and modeling.

Hal's work focused attention on the importance of local properties in influencing the reaction rate. He and his coworkers also demonstrated the usefulness of the activated-complex theory for simple gas-phase reactions when low-frequency vibrations were no longer neglected. Their series of studies of kinetic isotope effects, coupled with studies directed specifically at deducing the importance of tunneling, furnish a foundation upon which the field is still building.

Hal also contributed significant new experimental methods, including a sophisticated development in the direct study of transient intermediates. These laboratory studies of ozone and nitrogen oxide photochemistry constitute a body of work that paved the way for rapid progress in atmospheric chemistry related to these gases. Early on, Hal recognized the genius of chemist Arie Jan Haagen-Smit's proposal that Los Angeles smog was created by the photochemistry of organic compounds. In 1952 Hal proposed that free-radical reactions were at the heart of this chemical mechanism, a concept scientists now take for granted. In subsequent years his work continued to demonstrate the importance of elementary photochemical processes and free-radical catalysis in building an accurate description of atmospheric composition and in understanding the actual and potential effects of human activity on the atmosphere. Hal's perspective on ozone chemistry in the *Annual Reviews of Physical Chemistry* in 1992 provides a deeply personal account of his career. His life is also the subject of an oral history that resides in Berkeley's Bancroft library. Both documents provide rare insights into the personal reflections of one of the century's most influential atmospheric scientists.

While Hal was seriously dedicated to his work, he was also highly regarded by his students and colleagues for his sense of humor and caring attitude. Dudley Herschbach said that Hal once invited him on a hiking and camping trip after being called to a naval research lab to do consulting work. “To take a sophomore out to be his partner, visit a lab, go hiking and then talk about philosophy for four days—that’s pretty special,” Herschbach said. “How many undergraduates get a professor who personally is so much a wonderful friend and mentor?”

This sentiment was echoed by another “Johnstonite,” Joel Burley, who writes of his former mentor:

> *First and foremost, Hal was a true gentleman. He treated everybody with kindness and compassion; you never saw him raise his voice in anger, even during those instances when anger would have been justified. Despite his (many) world-class scientific contributions, there was never any ego or pretense coming from Hal—he instead emanated an unlimited supply of good humor and playful curiosity about the physical world. His inherent goodness was also omnidirectional and egalitarian, so that it didn’t matter if you were a lowly undergraduate or a Nobel Laureate or something in between—Hal treated everybody the same.*
>
> *During my time in the Johnston Group Hal and Mary Ella hosted a number of group dinners at their home up in the hills of Kensington. These were always very enjoyable affairs—good conversation, excellent food (usually fresh salmon), amazing views of the Bay Area sprawled out to the west, etc. After dinner we would always go downstairs so that Hal could fire up his audiophile-quality sound system and crank up some opera on the LaserDisk player. (It should be noted that Hal was a true connoisseur in these matters decades before surround-sound home theater systems became prevalent in suburban homes.) While loud, Wagnerian-style opera wasn’t necessarily everybody’s cup of tea, Hal’s enthusiasm was always highly contagious. He was like the proverbial kid in the candy shop, sharing his love (and knowledge) of good music and high-end audio gear with his guests. I really enjoyed those sessions, to the extent that I started attending live performances of the San Francisco Opera, comparing notes with Hal regarding the artistic merit of various productions or performers.*

Hal was also a good storyteller and had lots of amazing material to work with. His recollections ranged from his early childhood in Georgia to his work on poisonous gases during World War II to the "ozone wars" of the 1970's and 1980's. While much of the formal history associated with these events is a matter of public record, Hal was able to add in many fascinating details that were sometimes omitted from the official histories. It was therefore engrossing to get Hal's take on what had happened—while his recollections were unfailingly polite, they were also quite candid. These discussions motivated many Johnstonites to make the transition from pure research in gas-phase physical chemistry to applied research in atmospheric chemistry.

Hal retired in 1991— as far as I know, I was the last graduate student to complete a PhD under his supervision. But he stayed active on multiple fronts, and continued to do scientific work. A few years back, he approached me with an idea for a simple general chemistry experiment that would highlight certain calorimetric aspects of global warming. We quickly adapted his idea into an introductory lab here at Saint Mary's College, and then published our results in the Journal of Chemical Education *(2007, 2008). While this effort was obviously not cutting-edge research, it did demonstrate Hal's versatility, his innate talent as teacher, and his belief that scientists have a moral obligation to educate their fellow citizens. I remember thinking at the time that this was a brilliant idea for the teaching lab, and I wondered how it had come to Hal. But then I remembered that Hal's entire career had been one long string of brilliant ideas, and this particular contribution therefore seemed to be simply the latest iteration of a recurring theme."*

Hal's teaching style was unique as well. Graduate student Stephen Schwartz writes:

Hal (or "the boss" as we referred to him at the time, though not to his face) was a very good reader of human nature and of graduate student nature. He recognized that embarking on a PhD project was fraught with anxiety that would inhibit the student from working on it, so what he often did was to start students out on what he called a "warm up project." That way, you rolled up your sleeves and got to work, knowing in some way that this didn't count, so you could be free to mess up and *learn, because it was NOT your thesis. More often than not the warm up project became the thesis, without the student quite realizing it. Hal was a great skeptic of large computer models: Identify the key reactions and focus on them. Boil the problem down to its kernel. This skepticism underlay his critique (well after my time as a graduate student) of the proof (by multi-reaction computer model) that nitrogen oxides emitted from a proposed fleet of supersonic aircraft flying in the stratosphere would not have discernible influence on the stratospheric ozone layer. In a two-reaction model Hal was able to demonstrate, using the numbers provided by the proponents of such an aircraft fleet, that their computer model had to be wrong. The proponents were dismissive of Hal's simple proof, which only fired him up, leading to his famous paper in* Science *that put the nail in the coffin of the supersonic transport program. This is all recounted with some glee in Hal's 1992 article in* Annual Reviews of Physical Chemistry.

Hal was wise as well in having the patience to let his students learn on their own, instead of telling them the answer. In my case, I had the data, taken at very low pressure, but just couldn't make sense of them in terms of a physical model. It took me some months to realize that despite the low pressure, we were rapidly reaching a high-pressure limit. I am rather confident that Hal suspected this all along but wanted to let me discover that on my own. And I am grateful to him for not taking away my sense of discovery.

Hal didn't travel much in the days that I was his student, but one week he was gone. "Where's the boss?" someone asked, and someone else in the group responded that he had said that he was going to be in Washington for some kind of meeting. We found out later that the "some kind of meeting" was the meeting of the National Academy of Sciences at which he was inducted as a member.

Through his many awards, Hal was recognized as one of the giants of science. He was elected to the U.S. National Academy of Sciences in 1965 and was awarded an honorary D.Sc. from Emory University in the same year. Along with F. Sherwood Rowland and Mario J. Molina, he was awarded the 1983 Tyler Prize for Environmental Achievement for his *accomplishments in atmospheric chemistry. In 1985 the American Chemical Society bestowed on him the Award for Chemistry of Contemporary Technological Problems. In 1988 he was selected as the University of California Faculty Research Lecturer, the highest distinction of the Academic Senate at Berkeley. He received the President's National Medal of Science in 1997 and the American Geophysical Union's Roger Revelle Medal in 1998.*

Hal's Wife Mary Ella and two daughters, Linda and baby Barbara. 2-July 1969, taken at the Johnston Ranch. (Courtesy Leo Zafonte.)

Hal was married to Mary Ella for 64 years. They had four children: Shirley, Linda, David, and Barbara, and six grandchildren. Hal passed away from natural causes at his home in Kensington, California, on October 20, 2012, at the age of 92, far outliving all predictions of an early demise.

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Graduate Student Contributors:
John Birks

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Leo Zafonte.

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