Jacob Bigeleisen

1919–2010

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Alexander Van Hook

NATIONAL ACADEMY OF SCIENCES

JACOB **BIGELEISEN**

May 2, 1919–August 7, 2010

Elected to the NAS, 1966

Jacob Bigeleisen did seminal work in the 1940s on the effect of isotopic substitution on chemical equilibria and on isotope separation. For some 60 years thereafter he continued with studies of isotope effects on chemical kinetics, reaction mechanisms, and molecular and condensed phase properties, isotope effects in geochemistry, and refinements to the theory of isotope separations. Consequently his theoretical contributions have had an enormous effect on a number of areas of research. For example, the use of kinetic isotope effects to deduce mechanistic paths and transition state structures is now a major research tool in organic chemistry, biochemistry, and enzymatics, with hundreds of papers appearing each year.

By Alexander Van Hook[1]

Professor Bigeleisen's efforts, however, were not constrained to theory alone. He was responsible for a series of insightful experimental studies involving the effect of isotope substitution on condensed-phase properties of the rare gases, on a number of H/D substituted hydrocarbons, and on other molecules. Bigeleisen also played a key role in the development of most of the important isotope separation processes employed by the U. S. Department of Energy and its predecessor, the Atomic Energy Commission. Finally, Bigeleisen was extremely active in service to his profession, to university administration, to the National Academy of Sciences, and to the Gordon Research Conferences.

Early years

Jacob ("Jake") Bigeleisen was born in 1919 in Paterson, New Jersey, of immigrant parents. His mother (Ida Slomowitz Bigeleisen) and father (Harry Bigeleisen) had emigrated from a small village, Ozorkow (a suburb of Lodz, Poland), in 1910 and 1914, respectively. They were married in 1916. Jake was preceded by a sister (Esther) and followed by a second sister (Shirley). Harry Bigeleisen was a furrier, and in 1928 he started his own business, which he operated from the family home. The Bigeleisens were not poor, but according to Jake they were "less than lower-middle class." Everyone in the family worked long hours.

Jake recalled, "What I enjoyed most as a youth was school, particularly high school. Not so enjoyable were Hebrew school and religious services, which I attended every day for two hours, starting at age six and continuing until I was 13."[2] Jacob excelled at Eastside High School, where the enrollment was about 1,200. He enrolled in the classical curriculum, along with about 15 percent of his classmates. This was a rigorous program—four years of Latin, four of English, and three of German, three years of mathematics, two of social science, and one year each of chemistry and physics— and then a number of nonacademic subjects such as machine shop and gym.

Jake graduated in 1935, in the midst of the Depression, and there was little certainty of college. His father wanted him to learn a trade, but his mother was determined that he go to college. A family friend suggested chemistry because his (the friend's) brother-in-law owned a small dye house, one of many in Paterson, then known as the "Silk City." Each dye house had a chemist, which thus presented employment opportunities.

Jake's guidance counselor and Latin teacher, Miss Munchen Russak, encouraged him to apply to University College of New York University, located in the University Heights section of the Bronx. He was immediately accepted, but without financial aid for the first year. "I enrolled," Jake said, and "at University College I found out there was a whole world I never knew about—the excitement of doing research and discovering new knowledge. I never did look for a job in a dye house."[2]

Jake had an outstanding record at University Heights, winning a number of prestigious scholarships and awards, including election to Phi Beta Kappa. Upon graduation in 1939, at barely age 20, he had every expectation of acceptance into a graduate program at a premier university. However, this did not happen immediately, very likely because of the religious bias so widespread at the time.[3] Sometime in May, six weeks or so after the nominal April 1 notification date, Jake's older sister Esther asked why he had not applied to Columbia, and suggested that he go see Harold Urey, then chairman of the Chemistry Department.

After reviewing his transcript, Urey said he was late in applying for fall 1939 and applications to Columbia for that semester were now closed, but there was an outstanding refugee, Otto Redlich from Vienna, who had just joined Washington State College (now

Washington State University) in Pullman, WA, and who would need graduate students. Urey graciously forwarded Jake's credentials to Washington State. The result was that in September Jake was on the three-day/three-night train ride from Paterson to Pullman, his possessions in the small trunk that his mother had used when she traveled to the United States in 1910.

Graduate studies

Washington State College awarded Jake a half-time teaching assistantship, which paid $225 for the academic year, plus the commitment of an additional $100 from hourly wages at $0.35/hr. He enrolled in a master's degree program, even though the college had recently been authorized to award Ph.D. degrees. From the outset, Jake recognized that it was in his interest to get the Ph.D. from a major university.

For his master's thesis with Redlich, Jake devised a clever technique to make what was probably the first definitive measurement of the dissociation constant of a strong electrolyte. A comparison of the intensities of the nitrate lines in the Raman spectra of nitric acid/sodium nitrate solutions permitted him to accurately determine the dissociation constant of the acid, while eliminating the errors inherent in previous methods. This approach, which has stood the test of time, led to the development of rigorous experimental and theoretical criteria for distinguishing the association to form molecules from the association to form ion pairs. In addition to his work with Redlich, Jake took the opportunity at Washington State to get a good background in theoretical physics, including classical, quantum, and statistical mechanics. He studied all three subjects with Clarence Zener.

On the basis of his record at Washington State, Jake had no difficulty entering the Ph.D. program at the University of California, Berkeley. Within a week after his arrival in Berkeley in August 1941, he was apprenticed to Gilbert N. Lewis, the dean of the College of Chemistry (and more generally of American physical chemistry). At first, Jake supported himself with a teaching assistantship, but in December Lewis offered him a position as research assistant, thereby doubling his salary. Jake was one of the last two students of G. N. Lewis; the other was Michael Kasha.

Jake received his Ph.D. from Berkeley in 1943, with a thesis that explored the absorption spectra of aromatic molecules in rigid solvents. Lewis, working with David Lipkin, had earlier found that the photooxidation of aromatic molecules in such solvents, using polarized light, produced colored molecules with strongly polarized absorption spectra.

Jake applied this information in an ingenious way to ascertain the optical axes both of the irradiated molecules and their photochemical reaction products. The relationships he observed between (a) the directions of the optical axes of reactants and products and (b) between axis direction and molecular structures represented a significant extension of quasi-classical spectral theory for these molecules and paved the way for many subsequent developments in their spectroscopy and photochemistry. Jake worked out the physics of the relationships, but in presenting his results to Lewis he chose a coordinate system with the y- and z-axes in the plane of the board, and the x-axis perpendicular, with light traveling along the x-axis. Lewis stopped him at once with the statement, "In this laboratory, light travels along the z-axis." Jake had to go back and change all of his notation—no simple task. After Lewis then slowly went through the whole derivation once again, he declared, "I want you to write this up. Put it in your thesis. It doesn't matter what else you have in your thesis. It will be accepted." Jacob's Ph.D. thesis was only 28 pages long.[4]

Bigeleisen's spectroscopic work with Lewis was published in a series of eight papers in the *Journal of the American Chemical Society* in 1942 to1944. In a 2004 interview with Patrick Coffey, Jake described what it was like to write papers with Lewis—who dictated them without any notes: "Lewis did not like to cut into his research time for papers. We would meet in his office, where there was a large unabridged dictionary on a pedestal. [He] would simply dictate, and I would write. I would then read it back to him, and he would check words in the dictionary and make some changes. At this point he would say 'Get it typed up.'…On one of my eight papers he allowed me to write the experimental section, which I considered a great honor."[4] Jake told Coffey that shortly before he finished his work with Lewis, his rooming house caught fire. When Jake informed Lewis that he would need to take a few days off to find somewhere else to live, Lewis returned after lunch with the key to a room at the faculty club, which he had rented out of his own pocket. When Coffey said this seemed very generous, Jake replied that he thought Lewis just did not want him missing time in the laboratory. In any case, Ph.D. in hand, Jake left Berkeley in June 1943 to join the Manhattan Project at Columbia University in New York.

At the Manhattan Project

The primary mission of the SAM (Special Alloy Materials) laboratories of the Manhattan Project based at Columbia University and directed by Harold Urey was R&D support for the gaseous diffusion plant at Oak Ridge. However, SAM had also developed an improved process for heavy water production which was already in use at Trail, BC; and the lab carried out other research programs as fallback for gaseous diffusion. These latter included a gas centrifuge program in collaboration with J. W. Beams at the University of Virginia, a chemical process for separating uranium isotopes, a photo-process for separating uranium isotopes, and a boron isotope-separation process. Unknown to Jake, he had been recruited to work on the photo-process because of his expertise in spectroscopy and low-temperature photochemistry. A total of about 15 people worked on that program over its lifetime. The emphasis was on looking for differences in the spectra of ^{238}U and ^{235}U compounds. The most promising materials were the uranyl ($UO_2^{\ 2+}$) compounds, which had sharp line spectra. Maria Goeppert-Mayer, a theoretician, worked half-time on the project and had already made significant progress in understanding the vibronic spectra of uranyl salts.

Late in 1943, Urey asked Jake to calculate the differences in the isotopic properties of uranium compounds. It was this work that led directly to the development of isotope chemistry's reduced partition function ratio formalism, RPFR, which expresses the ratio of classical and quantum mechanical partition functions. When the request was made Maria Mayer was on sick leave, but on her return in early December she joined Bigeleisen in working out the details of RPFR. Using standard approximations, they showed (for the gas phase) that the logarithm of the RPFR is a simple function of the ratio of isotopic harmonic oscillator partition functions and directly yields the isotopic free energy difference and therefore the equilibrium constant defining isotope separation factors. Note that in the classical limit there are no equilibrium isotope effects and lim (ln (RPFR)) = 0. Thus the strength of the RPFR formalism rests on the fact that it focuses directly on the isotopic differences themselves, avoiding the difficulties inherent in methods that calculate the properties of each isotopomer separately in order to determine (very small) differences.

Remember that at the time—BC (before computers)—the high-precision calculations required to accurately define small differences between large numbers were extremely tedious and error-prone, as they involved at best the use of desktop mechanical calculators (essentially, adding machines). Using RPFR, the Bigeleisen-Mayer method led to a precision of (+/-)0.0001 even with a mechanical calculator.

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In any case, RPFR in hand, Urey reactivated the chemical separation program and Jake was assigned to calculate theoretical separation factors for uranium isotopes using various chemical processes. This effort was soon broadened to the calculation of separation factors for other isotopic pairs, including boron isotopes.

Johns Hopkins University had outstanding spectrographic facilities not available at Columbia, so in June 1944 Jake was detailed to Hopkins's Physics Department to continue work on the spectra of uranyl salts. He was recalled from Baltimore in January 1945 and reassigned to Willard Libby, who had succeeded Urey as the director of SAM. From time to time during the first half of 1945, Jake was given a week's leave to return to Baltimore and finish things up at Hopkins.

When the war ended in August 1945 and Jake was looking about for an appointment to an academic position, he received three unsolicited offers: the first from Clarence Zener, who was joining the University of Chicago as director of the Institute for Metals; the second from R. S. Mullikan, also at Chicago, but at the Laboratory for Molecular Structure, and the third from Herrick L. Johnston at Ohio State, who was investigating liquid hydrogen for use as a possible jet fuel. In late September, after conferring with Urey—the incoming director of the Institute for Nuclear Studies at Chicago (now the Enrico Fermi Institute)—Jake expressed his preference to join that institute. He had no formal offer as yet, but Urey was very definite. "He said I would be appointed a fellow, free to do my own research, with no teaching responsibilities," Jake recalled. "This was a two-year appointment. …Urey said it would fit best with their plans if I would go to Ohio State for a year and then come to Chicago. The deal was done."[5]

Marriage, Ohio State, Chicago

Jake married Grace Simon (also brought up in Paterson, just a few blocks from his parental home) on October 21, 1945, and after a short honeymoon in the Laurentians they left for Columbus. Over the next few years Grace and Jake had three sons: David, b.1948, currently an attorney in San Francisco; Ira, b.1951, a cantor in Los Angeles; and Paul, b. 1953, a research physician at the University of Maryland in Baltimore. The family ultimately expanded by three daughters-in-law and six grandchildren.

At Ohio State Jake worked for the best part of a year developing improvements for the storage of liquid hydrogen. He showed that except for insulating materials that reflect or scatter infrared radiation, the sole function of insulation is to reduce—or in the limit, to eliminate— convection of air and other gases between walls. In spite of his short stay with Johnston, the cryogenic experience gained at Ohio State served Jake well in later years when he was developing his experimental program to study condensed-phase isotope effects at temperatures as low as 20°K.

In July 1946 Jake and Grace left Columbus for Chicago. It was difficult to find a place to live, and the Bigeleisens variously stayed in rooms rented from several different faculty members, then finally in an army barracks that had been converted to faculty housing. At Chicago Jake found that the available spectrographs in the chemistry department were inadequate for his purpose. He therefore invested a good deal of time and effort in designing and building a suitable instrument. In addition, he volunteered to teach a recitation section in freshman chemistry and to share instruction in the physical chemistry laboratory.

Jacob Bigeleisen in 1989.

So far as Jake's future career was concerned his most important work at Chicago was the preparation for publication of research, just then declassified, done with Goeppert-Mayer at the SAM laboratory. Foremost was the influential paper "Calculation of Equilibrium Constants for Isotopic Exchange Reactions" (Bigeleisen and Goeppert-Mayer 1947). A second paper reported experimental measurement and theoretical analysis of the vibrational spectra of uranium hexafluoride and the calculation of its thermodynamic properties. The early-'40s SAM idea was to selectively remove ^{235}U from non-fissionable ^{238}U by utilizing light absorbed by the ^{235}U in one or another of its compounds. While this was impractical with the light sources available at the time, Jake's 1943-45 measurements proved to be highly useful in the design of the laser processes for uranium-isotope separation thoroughly investigated in the late-20th century.

Additional remarks on the Bigeleisen-Mayer Isotope Exchange Paper

The most important feature of the Bigeleisen-Mayer (BM) formulation is the insight that isotope effects on equilibria are vibrational quantum effects. Isotope effects therefore reflect changes in (isotope-independent) force constants at the positions of isotope substitution on the two sides of the equation describing the equilibrium. Thus for the first time, isotope effects were directly correlated to bond strengths. Bonds to the lighter isotope are easier to break than those to the heavier because of differences in the vibrational energy levels. It follows that the heavier isotope will favor chemical species in which it is bound most strongly.

On the basis of these principles, isotope effects have become important tools in many areas. Among these are new processes for isotope separation, the theory of the kinetic isotope effect and the use of kinetic isotope effects in the study of organic, biochemical, and enzyme reaction mechanisms, the theory of condensed phase isotope effects, discoveries relating to quantum effects in condensed matter, and the development of stable isotope geochemistry. The earliest use of the BM theory was its application to isotope separation. It allowed the prediction that uranium isotopes could be separated chemically and it led to chemical-exchange processes for enriching isotopes such as deuterium, tritium, ^{6}Li, ^{13}C, and ^{15}N. (For heavy metal isotopes, however, there are important nuclear-size and -shape corrections to RPFR calculated separation factors. These corrections can be as large, larger even than the vibrational contributions. Jake theoretically explained such unexpected effects in the 1990s, some 50 years after the BM paper!) By simplifying the problem of equilibrium isotope effects, the BM formulation opened up many possibilities for understanding natural processes. Isotopic abundances could now be interpreted in terms of the cycling of stable isotopes through chemical or physical processes, thereby generating a wealth of information.[6]

Twenty years At Brookhaven National Laboratory, 1948–1968

Jake left Chicago after two years, the term of his appointment. He could have stayed an additional year to capitalize on the time invested in building the spectrometer, but he jumped at the chance to join Brookhaven National Laboratory. BNL was a new facility being set up by the U.S. Atomic Energy Commission (AEC) to do fundamental research on the peaceful applications of atomic energy.

At Brookhaven Jake's career intensified. He began by formulating in 1949 the extension of the Bigeleisen-Mayer theory to kinetic isotope effects (KIEs), and his analysis showed that KIEs provide a method for investigating the properties of the transition state—that elusive entity that links reactants and products for a chemical reaction. Consequently, over the last 60 years KIEs have been a major research tool in mechanistic organic chemistry, biochemistry, and enzymology, with hundreds of publications appearing each year. KIEs are so useful because the linkage between first principles of isotope chemistry and the interpretation of experimental data in terms of reaction mechanisms is more reliable, more transparent, and better established than is any other method for quantitative interpretation of reaction mechanisms. That useful result is directly attributable to the influence of Jacob Bigeleisen and his coworkers, especially Max Wolfsberg and Ralph Weston, at Brookhaven in the mid-20th century.

During the Brookhaven years Jake contributed to research on virtually every large-scale isotope separation process developed in the United States. These processes included the production of heavy water, tritium enrichment, the separation of the lithium and boron isotopes, and uranium enrichment.

In the early days at Brookhaven Jake was heavily involved in studies of isotope separation. In 1950 he conceived the idea of producing heavy water by catalytic exchange between liquid ammonia and hydrogen gas. The basic work on the equilibrium and kinetics of the process were carried out at the BNL, but those results arrived too late to meet the requirements of the U.S. Savannah River Plant. Even so, Jake did serve as consultant to the Du Pont engineers in their design, which employed the dual-temperature H_2S/H_2O exchange process. A few years later the French adopted the NH_3/H_2 process for their heavy water plant at Mazingarbe. Other NH_3/H_2 plants were built in India and Argentina. In 1952 Jake served on an advisory committee of the AEC that determined the best process for separating lithium isotopes required for the thermonuclear program. From 1969 to 1990 he served as a consultant on uranium enrichment at Oak Ridge, participating in the major reviews of all processes for uranium enrichment during this period, and having a major impact on the selection of processes in current use. Jake's contributions to isotope separation led to the receipt of the 1964 E. O. Lawrence Award from President Lyndon Johnson. The award reads in part, "For outstanding experimental and theoretical contributions to isotope separation."

Also at Brookhaven, Bigeleisen began studies that extended equilibrium isotope theory in gases to solids and liquids. His initial theoretical paper on condensed phase isotope effects appeared in 1961. Concurrently with this theoretical advance, Jake was developing an experimental program to measure vapor-pressure isotope effects at high precision. The present author was involved in the early part of that experimental program together with Etienne Roth, Slobodan Ribnikar, and Marvin Stern. Vapor-pressure isotope-effect studies opened up a new field for the investigation of intermolecular forces and the motion of polyatomic molecules in liquids and solids. Particularly interesting have been the demonstration of quantummechanical translation-rotation coupling, the determination of barriers to hindered rotation, and symmetry controlled coupling of rotation with vibration in liquids and solids. Jake's later measurements of vapor-pressure isotope effects of the rare gases (mostly carried out at the University of Rochester and the State University of New York at Stony Brook) unambiguously established the relationship between the mean square force on a molecule in liquid or solid with the intermolecular potential and the radial distribution function.

In the mid-'60s, in collaboration with T. Ishida, Jake explored the use of finite orthogonal polynomials to obtain exact values for the nth-order quantum correction to harmonic oscillators and thence isotope effects via the BM formalism. Finite orthogonal polynomials provided a basis for the extension of the rules of isotope chemistry that Jake reported between 1955 and 57. These include, most notably, the rule of the geometric mean and certain other additive and cumulative rules dealing with multiple isotope substitutions.

The move to academia, 1968–1989

While still on the staff at the BNL Jake held visiting professorships at Cornell, the Swiss Federal Institute of Technology (Zürich), and the State University of New York at Buffalo. These experiences certainly influenced his decision to move from the BNL to the University of Rochester, 1968 to 1978. At Rochester Jake continued an active research program (funded by the U.S. Department of Energy) focusing on condensed-phase isotope effects. He served as chairman of the Department of Chemistry from 1970 to 1975 while maintaining his active role in research and teaching. At Rochester (and later), he taught honors freshman chemistry and graduate-level courses in thermodynamics and statistical mechanics. Jake's eldest son, David, commented, "Some professors find it a chore to teach freshman chemistry. Jacob felt otherwise. He made it a point of honor to teach freshmen."

In 1978 Jake moved to the State University of New York at Stony Brook as the vice president for research and dean of graduate studies. In addition to his administrative duties he continued to maintain his active research program in isotope chemistry, both experimental and theoretical. In 1980 he stepped down from administration, returning to full-time teaching and research as Leading Professor of Chemistry and later as a Distinguished Professor. Jake retired in 1989 but continued to carry out theoretical research on isotope effects at Stony Brook and later at his retirement home in Arlington, VA. Still working productively after his official retirement, he developed the theory of the fieldshift correction to the Bigeleisen-Mayer formalism; the correction arises from a shift in electronic energy states due to high charge density at the nucleus for atoms of high atomic weight. With this impressive theoretical analysis he quantitatively rationalized the anomalous chromatographic separation factors observed for uranium and other heavy metal isotopes.

Service to the profession

Jacob Bigeleisen was the prime mover in establishing the Gordon Conference on "The Chemistry and Physics of Isotopes" and served as chairman of the first meeting in 1954. The conference, which has continued annually or biennially ever since, attracts scientists interested in isotope separation and the applications of isotopes in geology, meteorology, medicine, biology, physics, and every area of chemistry. Jake's continuing presence at these meetings in effect stimulated the use of a rigorous and effective isotope effect formalism that has had seminal consequences for many fields, but most broadly and deeply for organic chemistry, biochemistry, and enzymology.

In 1968 Jake began a three-year term on the Board of Trustees of the Gordon Conferences and in 1970 was elected chairman of the board. That was a time when the organization was in a difficult transition period, and Jake was instrumental in reviewing the entire business operation and suggesting revisions and improvements that resulted in a firmer and more positive financial position. This time consuming but much appreciated work has materially contributed to the continuing excellence of the Gordon Conferences operation, which now sponsors some 150 different conferences each year.

Jacob was elected to the National Academy of Sciences (NAS) in 1966 and subsequently served it in a variety of positions. From 1976 through 1980, for example, he was chairman of the Assembly of Mathematical and Physical Sciences of the National Research Council, with operating responsibility for all programs and staff in these areas. Some of the major studies carried out during this time, with Jake's active participation, were:

- Need and Opportunities for Dedicated Synchrotron Radiation Facilities. This study led to upgrades of the Cornell, Wisconsin, and Stanford installations and to the construction of the National Synchrotron Light Source at Brookhaven. Later, dedicated facilities were built at Argonne and Lawrence Berkeley National Labs.
- A Usage Committee for the Hubble Telescope. This study resulted in the establishment of a facility at Johns Hopkins University to administer the Hubble program.
- A Naval Studies Board study that established new directions for the U.S. Navy's C3 (command, control, and communication) in the 1980s.

These examples are illustrative rather than exhaustive. They show that Jake devoted a major effort to his NAS activities and thus made important contributions to the profession and the nation.

In 1978 Bigeleisen was one of a group of scientists (mostly chemists), headed by Glenn Seaborg, that visited the People's Republic of China and toured a number of key universities, research facilities, and industrial sites. This was a time when mainland China was just becoming open to such official delegations. Jake gave lectures at several of these sites and contributed extensively to the report of the delegation, especially the section describing the state of isotope chemistry in China. The contacts resulting from this visit made an important contribution to U.S.-China relations in science and technology. Within a few years Jake hosted one of the first Chinese postdoctoral students to spend time in the United States. Invitations to Chinese scientists for visits to U.S. institutions and scientific meetings, including the Gordon Conference on Isotope Effects, soon followed. On a personal note, the author is sure that Jake's role in stimulating U.S.-China exchanges helped bring about the short term visiting professorship he held at Beijing University in the mid-'80s.

Other interests and accomplishments

Nothing illustrates the breadth of Jake's interests better than his accomplishments in architecture. Not long after their arrival at BNL, Grace and Jake settled on the design of a new house that they built at 47 Fairview Avenue in Bayport, NY, some 15 miles from the laboratory. They worked with an architect in formulating the details, which contained a number of Jacob's innovative features. As a consequence, perhaps, in 1959 he was appointed chair of the Building Committee for the new chemistry building at the BNL and his architectural interests thus shifted to the design of large buildings from the standpoint of efficient use by their human inhabitants. After interviewing a number of well-known architects for that building he joined forces with Marcel Breuer, and together they developed the concept of back-to-back research units with a utility core—a feature that is now widely employed both in industrial and academic research laboratories. The two remained good friends until Marcel's death in 1981. The building at BNL was written up a few years ago as one of several scientific buildings that have stood the test of time.

In one phase of the design for the BNL chemistry building, Jake was led to consider the problem of auditorium seating, and he concluded that the then-available seats were uncomfortable. So in collaboration with the American Seating Company, he formulated improved seating specifications. Later, his auditorium-seat design was also used by New York City's Lincoln Center and by the Kennedy Center and the NAS's Dryden Auditorium (both in Washington, DC), and he was especially proud of those choices. In 1998 Jake remarked that neither he nor any other member of the BNL's Building Committee financially benefited from the profits made by American Seating as a result of this design innovation.[7] He added the wry comment, "But we do have the satisfaction of comfortable seating in many of the auditoriums we visit." Later, Jacob's architectural interests continued to be on display in his homes in Rochester and St. James, NY (near Stony Brook), and in the apartment that Grace and he renovated in Arlington during their last few years.

Jake was widely read, and he and Grace very much enjoyed the cultural advantages of life in the New York City, Rochester, and Washington areas. They were regular and enthusiastic opera fans. Their homes were beautifully decorated with pieces of art, mostly modern, collected in their travels. Grace in particular was an accomplished fabric designer and connoisseur, as attested by wall hangings, rugs, and many articles of clothing. "In 1966 Grace persuaded Jake to buy a bright red Corvette Stingray coupe," their son David recalled. "It was quite a hot rod and took off like a bat out of hell. It was out of character for Jacob's mild manner. He drove it as if it were a sedate Oldsmobile."[8]

A personal note

I first met Jake in 1960 at a seminar he presented at Johns Hopkins. That meeting attracted me to BNL, where I spent one and one-half postdoctoral years working on vapor pressure isotope effects (an activity which continued for many years). Vicariously, however, my acquaintance goes back much earlier, as my parents grew up in Paterson within a few blocks of the Bigeleisen family. They attended the same elementary and high schools as Jake did (though not at the same time). Later, when Jake was working with Otto Redlich at Washington State College in Pullman, I was completing all requirements for graduation from kindergarten in Moscow, ID, some 20 miles down the road. Finally, my wife, who I met at BNL, grew up just a few houses away from the Bigeleisen home on Fairview Avenue, Bayport. In the 1970s and early '80s, the Bigeleisens visited with us in Tennessee during several of Jake's consulting trips to Oak Ridge. In later years we enjoyed a number of lunch and afternoon visits in the Bigeleisens' Arlington apartment during our annual trips to Washington and New York. We remember Jake and Grace fondly.

Final words

Throughout his career Jacob was scrupulously fair in his judgments, though I had many a battle with him as reviewer (more often as reviewee). On these occasions he always identified himself and presented his arguments objectively, albeit forcefully. He was invariably careful to protect his scientific interests.

Earlier in his career Jake suffered considerable religious prejudice, especially when applying to certain Ivy League graduate schools, which at the time practiced an unwritten "quota" system; it is this that sent him off to Washington State (ultimately to his benefit). He was ever grateful to Harold Urey's role in that move. Later he much regretted the policies in American universities that restricted Maria Goeppert-Mayer's role to volunteer research associate, even as late as 1945. Several times in conversation with this author, he pointed out that Maria's experience underscored the shameful customs of American academia that severely limited opportunities for women. Late in life he was grateful for the progress that had occurred in both of these areas, though he was ever looking for more.

Jake had a fertile mind and a sharp wit. In addition to his considerable mathematical skills, he had unusually keen insights into physical phenomena that he was able to communicate to his colleagues. In this fashion, he stimulated research on isotope effects in many laboratories across the world, and on a wide variety of topics.

Jacob Bigeleisen was a truly fine thinker, an excellent scientist, a capable administrator, and an outstanding public servant. I am honored to have known him and to have worked with him.

ACKNOWLEDGEMENT

The author thanks the Bigeleisen family, particularly David Bigeleisen, for their cooperation and helpful comments. These contributions have materially improved this presentation.

COLLABORATORS OF JACOB BIGELEISEN

Otto Redlich*	1942–43**
Gilbert N. Lewis*	1942–44
Maria Goeppert-Mayer*	1947–48
Lewis Friedman*	1949–53
Ralph E. Weston, Jr.	1952–63
Max Wolfsberg	1953–69
Eugene C. Kerr	1955
Fritz S. Klein*	1959
Etienne Roth*	1960–61
Slobodan V. Ribnikar*	1961–77
W. Alexander Van Hook	1961–63
Marvin J. Stern*	1963
Takanobu Ishida	1968–81
William Spindel*	1968–71
James T. Phillips	1972
Carl U. Linderstrom-Lang*	1972
Myung W. Lee*	1974–82
Frederic Mandel	1973–75
Yumio Yato	1975–77
Masahiro Kotaka	1992
Anthony M. Popowicz	1991
Luis P . N. Rebelo	2002–03

This table has been modified from Bigeleisen, 2006. The first two entries were added by the present author.

* Deceased

** This column denotes the years of first and last coauthored publication; continuous collaboration over the entire period is not implied.

SELECTED HONORS

Member of the National Academy of Sciences, elected 1966

Senior NSF Postdoctoral Fellow, Tech. Hochschule, Zürich, 1962–63

Guggenheim Fellow, 1974–75

E. O. Lawrence Award and Presidential Citation, 1964

Am. Chem. Soc. Nuclear Applications Award, 1958

Inscribed at the Technion, Haifa, Israel

Tracey Harris Professor, Rochester, 1973–78

Leading Professor of Chemistry, SUNY-SB, 1978–89

Distinguished Professor, Emeritus, SUNY-SB, 1989–2010

NOTES

1. Ziegler Professor of Chemistry, Emeritus, University of Tennessee. (avanhook@utk.edu)

2. Bigeleisen, J. 1989. Informal remarks on the occasion of the Bigeleisen Isotope Symposium, May 6. 1989. *Proceedings* edited by T. Ishida, M. Saunders, W. A. Van Hook, and M. Wolfsberg. *Zeitschrift Naturforschung* 44A:337–493.

3. Bigeleisen applied to five prestigious universities and was turned down by all in spite of his outstanding academic record. Very likely one or more of his referees had given him negative recommendations on a personal level.

4. Coffey, P. 2008. *Cathedrals of science: The personalities and rivalries that made modern chemistry*. New York: Oxford University Press.

5. Bigeleisen, J. *Harold Urey in my life.* Informal remarks prepared for the Harold Urey Memorial Service, University of California at San Diego 1981. Manuscript copy communicated, JB to AVH, 2005.

6. Rouhi, M. 1997. The world of isotope effects. *Chem. Eng. News*, Dec. 22:38–42.

7. Bigeleisen, J. 1998. Letter to C. Creutz, April 10.

8. Bigeleisen, D. 2013. Personal communication to the author.

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Jacob Bigeleisen authored or coauthored some 135 papers in the scientific literature, plus 10 book chapters and six articles dealing with public implications of science policy. A selected list follows.

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