BIOGRAPHICAL MEMOIRS

C. Bradley Moore

December 7, 1939–September 27, 2025
Elected to the NAS, 1986

A Biographical Memoir by Stephen R. Leone

C. Bradley "Brad" Moore was a giant in the field of laser chemistry and spectroscopy. As a beginning assistant professor at the University of California, Berkeley, he recognized the advantages of newly discovered lasers, especially pulsed lasers, to pioneer previously inaccessible mechanisms of state-resolved processes in molecular energy transfer, photochemistry, and transition state dynamics. During his more than forty years at Berkeley, Brad masterfully guided his research group to highly impactful results in modern state-resolved physical chemistry. He also shepherded the institution and colleagues by passionately executing leadership positions as vice chair and chair of the Department of Chemistry, dean of the College of Chemistry, and director of the Chemical Sciences Division at Lawrence Berkeley National Laboratory. He established new fields, built campus infrastructure, developed undergraduate instruction, collaborated with and helped numerous colleagues, and produced innumerable highly accomplished students, leaving a lasting legacy for chemistry at Berkeley.

Seeking a level of impact that was broader than just chemistry, he was the founding chair of the National Academy of Sciences (NAS) Committee on Undergraduate Science Education. He became a vice president for research, first at The Ohio State University and then at Northwestern University, enhancing the research portfolios and providing strategic leadership in research at both campuses, all the while promoting the marvels and accomplishments of such diverse disciplines as math and medicine. Back at Berkeley as an emeritus professor, he took on additional NAS committee work and university fundraising, and he was the person who always had the most perceptive scientific questions and insights at group seminars and coffee with colleagues at Strada coffee shop. When Brad passed in 2025, the world lost a remarkable and caring person, a husband to Penelope Percival and father to Scott and Megan, a hard-core cyclist, dancer, and enthusiastic sailor, and a scientist of unsurpassable and indefatigable creativity, rigor, and insight.

Figure 1 C. Bradley Moore, Vice President for Research, Northwestern University. *Courtesy of Northwestern University*.

Early Life and Education

C. Bradley Moore was born on December 7, 1939, in Boston, Massachusetts, the son of Charles Walton Moore and Dorothy Moore. His father was a self-taught chemical

Figure 2 With Shadow, the family dog. *Penelope Moore family photos.*

engineer who had worked as a laboratory assistant to Thomas Edison, and Brad grew up on their farm in Pennsylvania. Central to his physical chemistry experimental skills, Brad learned from his father how to take apart, fix, and rebuild farm equipment. Also on the farm, he acquired the discipline to grow crops and tend livestock. In his curious times, he produced his own gunpowder for experiments, which probably led to at least some level of his fearlessness to make and dissociate explosive precursors of methylene for his Ph.D. thesis. Brad was lucky enough to attend one of the amazing and explosive chemistry demonstration seminars of Princeton professor Hubert Alyea (nicknamed "Dr. Boom" and the inspiration for Disney's *The Absent-Minded Professor*) on the wonders of chemistry at a local high school. Brad was mesmerized by Alyea's demonstration of breathing out smoke from dry ice in his mouth (definitely not recommended by safety experts), and that lecture experience seemed a central turning point in focusing Brad's scientific interests toward chemistry.

Brad attended Exeter Academy in New Hampshire for high school, a visionary school with a rich history, many famous alums, and an exceptional chemistry professor, Charles L. Bickel, who wrote a textbook on experimental chemistry. Bickel's classes gave Brad the final impetus to pursue chemistry as a career. Moreover, Exeter was sufficiently forward-thinking at the time to invite J. Robert Oppenheimer for a week-long visit to talk with students after Oppenheimer's hearings and revocation of security clearance by the U.S. government. That visit made a deep impression on Brad, the other students, and faculty. When a conservative New Hampshire newspaper criticized Exeter for allowing Oppenheimer to pollute the minds of Exeter's students, Brad defended Exeter in a letter to the editor and retorted that the newspaper should get its own house in order because of their heavy-handed political influence in New Hampshire primary politics. Even in a high school academy, Brad's character stands out: viewing the world with an open mind, following the logic, drawing his own conclusions, and doing what is right.

In 1957, Brad entered Harvard University, declared chemistry as a major, and worked on research projects in the physical organic chemistry laboratory of Paul D. Bartlett. Graduating from Harvard magna cum laude in 1960, having gained additional experience through summer jobs at both Arthur D. Little and General Electric, and with a National Science Foundation (NSF) graduate fellowship in hand, Brad moved to Berkeley and joined George Pimentel's group in the Department of Chemistry.

More important than that, Brad married Penelope Percival, his dearest from high school days, in August 1960, leaving that same day to drive together to Berkeley. They met at a dance between Penny's and Brad's high schools, and Brad paid Penny's escort fifty cents to have the last dance with her. Brad was an excellent dancer, and they always took every opportunity to dance throughout life, especially at NAS spring meetings. Penny became his lifelong partner, and in Brad's own words in an *Annual Review of Physical Chemistry* article, he described Penny as "a great partner, protector, mother, home builder, educator, author, sportswoman, and hostess to research group members, faculty colleagues, friends from around the world, and present and future university donors." Penny earned her undergraduate degree in physics at Berkeley, was a graduate student with Luis Alvarez, and developed a career as an educator. She became a faculty member at Piedmont High School and served as director of Berkeley's Science for Science Teachers program and was the lead author of a series of textbooks called PRIME Science, both NSF initiatives involving curriculum development and improving science instruction, for which Penny wrote the proposals. Penny deftly bridged the void between K–12 and university education, frequently representing both Piedmont High School and Berkeley.

Berkeley and Early Research

On arriving at Berkeley, Brad was most intrigued by a project outlined by George Pimentel, who suggested it would

only take six months. It was to produce methylene, CH_2, by trapping photolytic precursor molecules in solid rare gas matrices at low temperature, then generate the CH_2 radicals by photolysis, and finally acquire infrared spectra of this elusive carbene radical. Methylene has formed the scientific basis for numerous scientific careers. This smallest carbene has two unbonded electrons, high reactivity, and a pair of singlet and triplet states with often-disputed energies, each with different geometrical configurations. Ketene molecules, diazirine, and diazomethane were candidate precursor molecules for Brad to try, but the latter chemicals were hazardously explosive. When the first explosion occurred for Brad, Penny started staying with Brad overnight in the lab, at his request, as there was no one else around late at night when Brad was patched up at Cowell Hospital at 2 a.m. Brad's research did not obtain the desired infrared spectrum methylene, for which he was most apologetic and thanked George Pimentel for approving his thesis topic anyway.

Yet, he did obtain many detailed and original spectra of the precursor molecules themselves, leading to exacting measurements and models that Brad developed for the low frequencies of the CH_2 bending potentials and the spectroscopic intensities of these modes in the various precursor molecules. Moreover, through clever isotopic substitutions, Brad obtained indirect proof that CH_2 was being formed in the matrix photolysis process, as the carbene reacted quickly with nitrogen to create diazomethane molecules trapped in the matrix with altered isotopic composition. Two decades later, with more advanced techniques of laser spectroscopy, Brad's own research group ultimately recorded the infrared spectrum of methylene.

In those days, it was possible to go onto the academic job market without having had a postdoctoral position, and this is what Brad did in 1963 in his third year of graduate school. With many interviews, Berkeley was the one university that gave Brad a coveted assistant professor offer. Notwithstanding the unsuccessful infrared spectrum of methylene, Berkeley had insider information about Brad's potential. Berkeley has some of the best students, and Berkeley chemistry was never afraid to entice those students to become their faculty. Brad continued his connections to Pimentel's group over an extended time via joint group seminars early in his career and thus was exposed to novel aspects of the research it conducted. The easy flow of ideas and the always-questioning climate between Brad's group and Pimentel's group were highly beneficial for Brad. Low-temperature infrared detectors and circular variable filters employed by Pimentel's group in the Mariner Mars projects and laboratory rapid scan infrared spectrometers, and the discoveries of chemical lasers, would play key roles in what would happen next in Brad's nascent independent laboratory.

Research Breakthroughs

In 1960, the first ruby laser was invented by Theodore Maiman, and in July 1963, Brad was hired by Berkeley. Having worked with Pimentel during his graduate studies, Brad knew he had to do something quite different to stand out as a young faculty member. What he chose was prescient. Realizing the potential of laser sources to excite molecules to study chemical dynamics and understanding the historical work and theories of molecular energy transfer, he sought to measure kinetic rate constants of vibrational relaxation and energy transfer with lasers, rather than shock tubes and continuous lamps. Brad employed many of the newly emerging continuous and pulsed laser sources that were being discovered, in particular leveraging home-built laser systems in his own lab, together with sensitive infrared detectors that only became available through the space program, to establish a blossoming new field of measuring rate constants of molecular energy transfer.

Several prongs developed quickly in Brad's new laboratory on the third floor of Lewis Hall. He used vacuum ultraviolet light to study electronic energy transfer and relaxation of hydrogen molecules. He and his students also used the 3.39-micron infrared line of a continuous home-built helium neon laser to excite methane molecules to observe vibrational mode-to-mode energy transfer in a small molecule. The group built pulsed hydrogen halide lasers (first proposed by John Polanyi and later achieved by Kasper and Pimentel) specifically to excite hydrogen halide molecules for expansive studies of vibrational energy transfer. His group formulated the fundamental rules and validated the theories for vibration-to-vibration (V-V), vibration-to-rotation (V-R), and vibration-to-translation (V-T) energy transfer processes. Notably, the important role of V-R energy transfer was verified directly by Brad's research. Electric-discharge-excited CO_2 lasers were used to map the energy transfer processes and rates in this notable molecule. CO_2 rates and energy transfer became very important because of the extraordinarily powerful infrared laser that CO_2 makes, which, even to this day, has so many commercial applications in marking, cutting, drilling, and engraving.

Also, shortly after the development of lasers, the field of nonlinear optics was born, the simplest example of which was the production of efficient frequency-doubled light with nonlinear crystals. Brad recognized that the frequency-doubled output of a ruby laser matched the ultraviolet electronic transitions of formaldehyde and thus studies of the ultraviolet photophysics of formaldehyde became his lifelong passion. Brad was quick to adopt all the latest laser and detection technology. Within a few years, the group was implementing tunable optical parametric oscillators, producing discharge flow tubes to study energy transfer with reactive

Figure 3 Lippencott Prize, *Courtesy of Optical Society of America (now Optica).*

atoms and harnessing lasers to produce atoms by photolysis for reactive and isotopic-selective studies. Brad's group pushed the limits of all forms of laser technologies and high-performance light detection in measuring state-resolved processes of molecular dynamics, reactive chemistry, and transition states.

Among the many contributions of the Moore laboratories at Berkeley, several created a lasting legacy. He rewrote the data and rule books regarding our understanding of the V-V and V-R translation types of energy transfer in collisions. The basic principle to preserve internal excitation, whenever possible, provided a key framework to understand a wide range of molecular energy transfer phenomena. For example, one quantum of an overtone vibration could rapidly form two quanta of the fundamental vibration in collision with a ground state molecule, preserving internal energy, or one quantum of vibration could form high rotational states rather than deliver the full vibrational excitation in one impulsive kick to translation with a rare gas atom collision. Collisions with reactive atoms rapidly removed vibrational excitation one thousand times faster than closed-shell atoms and molecules. These insights would not have been possible without the state-resolved viewpoint that Brad introduced to the field and the many precision, laser-excited measurements of his group.

In one of Brad's seminal experiments, he proved that a higher energy vibrational mode in a polyatomic molecule, methane, could transfer its energy to a lower energy mode in the same molecule by intramolecular energy transfer. Such information translated immediately to a wide array of intramolecular dynamics, whereupon such processes as a one-to-two resonant energy transfer from a higher energy mode to two lower energy modes became central to understanding rapid intramolecular energy transfer events.

The formaldehyde molecule (H_2CO) was one of Brad's enduring interests, and his recognition of the competition between unimolecular dissociation and energy transfer led to one of the first concrete examples of laser isotope separation. The ever-increasing detail of formaldehyde photophysics in Brad's work led to the discovery of an anomaly that would eventually be attributed to the roaming atom mechanism. At just the right total energy, one of the H atoms can nearly depart the formaldehyde molecule and undergo a complex trajectory surrounding the HCO radical, eventually abstracting the other H atom to form H_2 and CO, while causing the CO molecule to be produced in unusually high rotational states. Brad conducted his work discussing the unusual state-resolved processes that occurred above and below a specific energy in 1993, and Joel Bowman, Arthur Suits, and others identified the specific interaction as a roaming trajectory in a 2004 *Science* paper using velocity map imaging.

Much of Brad's career was spent in the pursuit of the types of unimolecular dissociation transition states that occur in molecules, the shapes of the barrier crossings, and the effects that those transition states have on the resultant state-resolved processes. In particular, the molecule ketene (CH_2CO) was another subject that had captured Brad's attention starting in the early days of his Ph. D. thesis research in trying to record the methylene (CH_2) spectrum by dissociating ketene in a rare gas matrix. With ketene, he later tested unimolecular dissociation theory in great detail and established the role of singlet versus triplet channels, showing that various channels opened in a stepwise fashion versus energy. His work took major forays into bond selective chemistry, ultrafast phenomena, and conical intersections. Given Brad's pioneering influence on the use of lasers in chemistry, it was fitting that he took the initiative to edit a five-volume series of books entitled *Chemical and Biochemical Applications of Lasers.* A sixth book, edited by Michael Berman, Linda Young, and Hai-Lung Dai, titled *Emerging Trends in Chemical Applications of Lasers,* was presented to Brad in honor of his eighty-fifth birthday; it collected the papers presented at an American Chemical Society meeting symposium on his eightieth birthday.

Mentorship and Collaboration

Remarkable teams of Ph.D. students, postdocs, visitors, and undergraduate students came through the Brad Moore laboratories over multiple "generations," and the instrumentation that Brad obtained for the labs became ever more sophisticated. Looking back, the lab was extraordinarily cutting edge in terms of laser and detector technology even in its earliest days. Numerous collaborators took an interest in the results of the lab over the years, resulting in important and wide-ranging theoretical and experimental cooperations. Nearly every year, someone from the lab was seeking and taking up an academic position or establishing a lab somewhere else in the world. Others were filling key positions in corporations and national labs and agencies.

With so many highly successful former students and postdocs, no doubt each person has an important story to tell about their interactions with Brad during their "generation" as they stepped out to become independent. A few of these are captured in the detailed obituary provided by the American Chemical Society about Brad's life that was published in *Chemical and Engineering News*. A constant throughout all of it, though, is the rigor and resourcefulness that each of these individuals brought to their positions. Such qualities arose from the level of independence and trust that Brad gave to each member of his research group, and the expectations and goals that he set. Brad never told us exactly what to do, he instilled in us the ability to create, to investigate with rigor, and to deliver with principle. He set examples through the passion he brought to the science, the penetrating questions he asked, and his deep commitment to doing every job well.

Leadership Outside the Laboratory

Brad brought that same commitment to the many administrative positions he held at the University of California and Lawrence Berkeley National Laboratory. In what would normally seem to be burdensome tasks, such as being department chair or dean of a college, Brad used these positions to attain his goals of helping colleagues, building infrastructure, and promoting and hiring outstanding people. He was central in spearheading the funding to build Tan Kah Kee Hall, in helping colleagues through rough times, and in constantly promoting the outcomes and successes of Berkeley's College of Chemistry.

In his later years, Brad moved to The Ohio State University and then to Northwestern University, serving as vice president for research at each institution, with a goal to make a greater impact with research across multiple scientific disciplines. In both cases, he encouraged and built programs of interdisciplinary science and oversaw a broad increase in research funding portfolios. Northwestern University already had a tremendous legacy and success with interdisciplinary

Figure 4 In retirement. *Penelope Moore family photos.*

research centers; Brad guided it to join with other institutions in the region in the management of Argonne National Laboratory and Fermi National Laboratory, actions that have had long-lasting impacts on science and faculty through joint appointments and access to facilities. When Brad joined Northwestern, the university was under federal pressure regarding underperforming research management, and Brad established new offices to improve research integrity and grants administration so that the scrutiny was lifted, and growth and faculty productivity expanded for decades afterward.

On the national scene, Brad was very active in the NAS, being the founding chair of the Committee on Undergraduate Science Education and participating on the Panel for Chemical Physics, the Committee on Atomic, Molecular, and Optical Sciences, the AFOSR Chemical Sciences Review Panel, the advisory board to the National Research Council's Center for Science, Mathematics, and Engineering Education, the Committee on Information Technology, and the working group on Science Content Standards for the National Science Education Standards. His contributions to so many educational initiatives mirror Brad's honoring of the importance he held for Penny's career and his passion for teaching in the College of Chemistry at Berkeley. Even after reaching emeritus status back at Berkeley, Brad found

Figure 5 In Boulder, Colorado. *Stephen Leone photos, retouched by Megan McA'Nulty.*

time to chair the NAS report *Assuring a Future U.S.-based Nuclear and Radiochemistry Expertise* and help with Berkeley's fundraising.

Final Thoughts

Brad Moore was as man of great originality in science and technology, a person of incredible perception and problem-solving ability, and someone with a way of working with people to produce better outcomes with fairness to all. He introduced lasers into chemistry at the state-of-the-art at a time when scientists had to build the lasers with their own hands, and he made laser chemistry and spectroscopy a visionary new field in physical chemistry. In addition to his lasting contributions to science and keen abilities in administration, Brad will be remembered for his avid cycling. Cycling seventy miles in the hills on an afternoon was Brad's passion and norm. He brought his bicycle to Boulder, Colorado, while on a sabbatical as a JILA (Joint Institute for Laboratory Astrophysics) Visiting Fellow in 1980–81, and he was in high-altitude heaven. The Moore home on Oxford Street, where we gathered so many times for group parties, the trips to Yosemite, the many versions of their dog Shadow, their children Scott and Megan, and the help that Brad charitably gave to his students and colleagues will always be remembered.

Note

Key articles were used in assembling this memoir: P. L. Houston and S. R. Leone, 2000, "Biography of Professor C. Bradley Moore," part of the special festschrift issue of *J. Phys. Chem. A,* 104:10059; C. B. Moore, 2007, "A spectroscopist's view of energy states, energy transfers, and chemical reactions," *Annu. Rev. Phys. Chem.* 58:1; S. Cottle, Obituary: C. B. Moore, *Chem. Eng. News,* October 15, 2025; and personal notes from former student James T. Yardley.

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