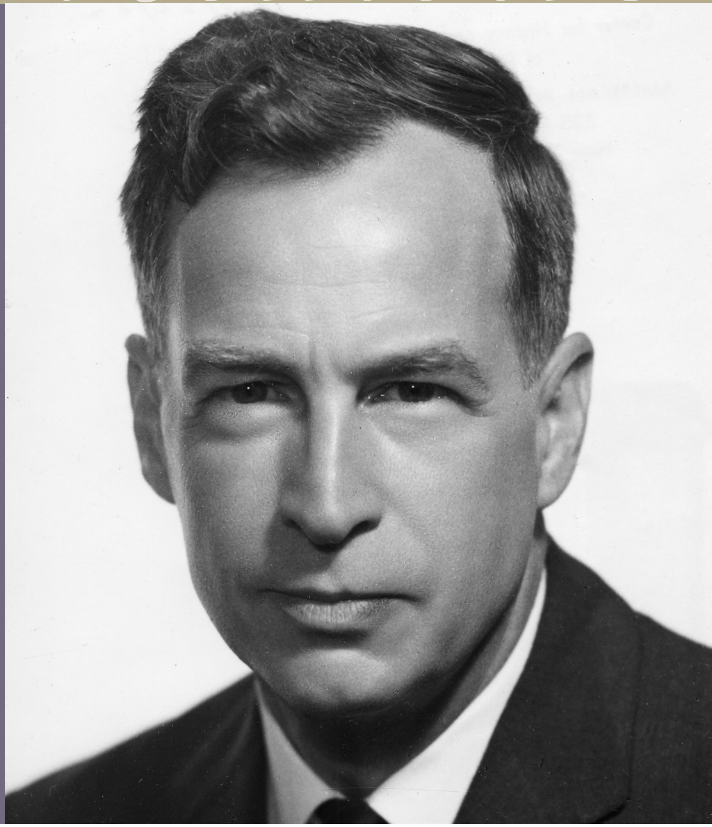
E. Bright Wilson Jr.

1908–1992

BIOGRAPHICAL *Memoirs*



A Biographical Memoir by
Dudley R. Herschbach

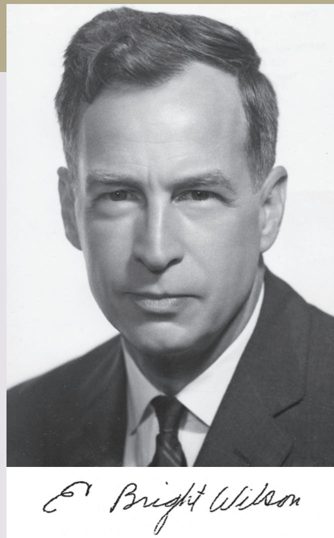
NATIONAL ACADEMY OF SCIENCES

EDGAR BRIGHT **WILSON** JR

December 18, 1908–July 12, 1992

Elected to the NAS, 1947

In his research, Bright Wilson became a major architect of chemical physics. He provided definitive theoretical treatments of molecular vibrational and rotational dynamics, especially symmetry analysis. With his students, he developed key experimental apparatus and techniques in infrared and microwave spectroscopy. As well, he fostered aspects of thermodynamics, statistical mechanics, electronic structure, and quantum chemistry. In his teaching, Bright also was fully devoted, giving original treatments of introductory and advanced courses, including philosophy and the history of scientific research.



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By Dudley R. Herschbach

Early Years, Eager for Research, at Princeton

Bright was born in Gallatin, Tennessee, but grew up in Yonkers, then a fashionable suburb of New York. His mother, Alma Lackey, came from a family with deep southern roots. His father, E. B. Wilson, was a lawyer, admitted to the Tennessee bar but practiced corporate law in New York City after the family's move. In his early teens, Bright undertook chemical experiments at home, built radio receivers, and obtained an amateur radio license. Such interests were unprecedented in his family. On occasions, Bright told of his excitement when, as a high-school boy of 15, he discovered in the town library a newly published book, the now classic text by Lewis and Randall, *Thermodynamics and the Free Energy of Chemical Substances*. That book first revealed to Bright the grand scope and logical beauty of science, which he pursued ardently thereafter. To appreciate how remarkable this episode is, you need to know that the Lewis and Randall book and its clones or descendants have over the intervening years been strictly graduate-level texts. Today it seems amazing that a high-school lad could be captivated by such a book—and that a town library had acquired it.

In 1926, Bright enrolled at Princeton. In his freshman year, only 18, he asked "to do some research." That led to his first paper, about a continuous reading method of electrometric titration with bimetallic electrodes. Bright later recounted: "My contribution to this work was largely ignorance, but it has always served me as an example of where too great a knowledge of one's subject may sometimes be a handicap, since my ignorance of an unconventional approach did actually work."

At Princeton, his major was chemistry but he took many physics courses. He recalled studying very hard to "cut my quantum mechanical teeth." He learned much from two newly hatched books on quantum theory: one by Edward Condon and Philip Morse, the other by John von Neumann. Bright also had some discussion with Eugene Wigner about group theory. These authors were all Princeton physics faculty. As a senior and a first-year graduate student, Bright eagerly attended physics colloquia but noted, "I didn't understand some at all.…Perhaps this accounts for my lifelong complacency with my ignorance."

He pursued research projects with chemistry faculty, chiefly C. P. Smyth and W. T. Richards. For two summers Richards brought Bright along as a guest of the fabled Loomis Laboratory at Tuxedo Park, New York. There Bright met Professor Robert W. Wood, esteemed for his experimental wizardry in spectroscopy. Back at Princeton, Richards also introduced Bright to a faculty colleague, another wizard of experimental chemistry, George B. Kistiakowsky. Bright was destined to see much of both spectroscopy and of Kisty.

Upon graduation in 1930, his parents financed a summer trip for Bright to Europe. Princeton had just opened the Frick Chemical Laboratory with visiting chemistry notables. W. T. Richards gave Bright letters of introduction to some of the dignitaries for his trip. For instance, Bright recalled that Michael Polanyi personally showed "this green kid all around his lab in Berlin-Dahlem as if I were an important person." Bright also met Peter Debye, then in Leipzig, and some others. Twenty-five years later, Bright would be the department chairman welcoming Debye as a visiting lecturer at Harvard.

Onward to Caltech

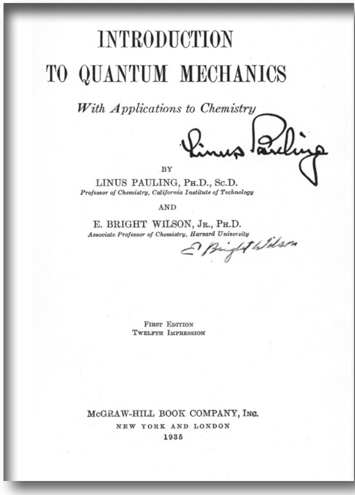
After earning his B.S. in 1930 and M.S. in 1931, both in chemistry, and having turned out four experimental papers, Bright headed west to the California Institute of Technology (Caltech), to work with the brilliant young theorist Linus Pauling. The trip was made with a couple of friends in a sturdy touring car. It had to be sturdy, as Bright liked to emphasize, because in those days the long road across the southwestern desert consisted of logs laid crosswise in the sand. As expected, he found Pauling was awesome and inspiring. Quantum mechanics had emerged just as Pauling got his Ph.D. in 1925 at Caltech. A fellowship had enabled him to travel in Europe for two years, to study under Arnold Sommerfeld, Niels Bohr, and Erwin Schrodinger. Then Pauling returned to make Caltech the mecca for structural chemistry.

Most graduate students in Pauling's group were involved in experimental work, mainly crystal structure determinations. Bright was assigned that work, but he recalled that his morale faltered. He had done a lot of experimental work at Princeton, yet at Caltech he "struggled with trivial practical difficulties in the lab.…Pauling rescued me…and proposed a quantum mechanical calculation…on the lithium atom." Bright completed his Ph.D. in just two years while also teaching freshman chemistry sections and assisting Pauling with his quantum mechanics course.

The Caltech Chemistry Department had a rule, not rescinded until some years later, that required every Ph.D. thesis to include experimental work. Pauling had Bright honor this rule by measuring the magnetic susceptibilities of several nitroso compounds. This was done using a Gouy balance borrowed from the Mount Wilson observatory and transported to Pasadena in Pauling's roadster. Bright's results disproved a pet theory of his mentor. Cheerfully, Bright stressed this episode as a cautionary tale for his graduate students. The Caltech rule reflected the strong cultural bias most chemists then had against mathematical theory. For instance, the *Journal of Physical Chemistry* (*JPC*) refused to accept purely theoretical papers until the late 1940s; *Chemical Abstracts* often dismissed such papers with a four-letter entry: "math." The consequence was a new journal published in 1933: *Journal of Chemical Physics*. In the first issue, Bright published solo his first theoretical paper, drawn from his Ph.D. thesis.

In his second year at Caltech, Bright was invited by Pauling to have a third year as a post-doctoral fellow. He gladly accepted and undertook with Linus to write a textbook, *Introduction to Quantum Mechanics*. It became a celebrated book, accessible to both fledgling chemists and physicists. Published in 1935, it was still in print beyond 2000 and many other texts borrowed liberally from it. When asked years later, Bright said he labored over several drafts but he couldn't remember which chapters he did. He was sure Linus wrote about two-thirds of the book and corrected Bright's input; when "Linus wrote something, it stayed that way." Bright was delighted to hear that Richard Feynman, when he was in high-school, first learned quantum mechanics from the Pauling and Wilson book.

In his postdoctoral year, Bright found "Pauling was very generous in allowing me to do what I wanted." Through courses and colloquia, Bright learned about molecular vibrations and normal coordinates. Also, he came across an article by George Kimbell and Henry Eyring on the application of group theory to treatment of electronic aspects of symmetrical molecules. Bright realized the same methods could be applied to the normal coordinate vibration problem. He found that "tremendously exciting," and produced solo papers treating the application of group theory and symmetry analysis to the interpretation of molecular spectra. Among them were landmark studies of the vibrational modes of benzene and the nuclear spin statistics imposed by the Pauli principle.



INTRODUCTION
TO QUANTUM MECHANICS
With Applications to Chemistry
Linus Pauling
BY
LINUS PAULING, Ph.D., Sc.D.
Professor of Chemistry, California Institute of Technology
AND
E. BRIGHT WILSON, Jr., Ph.D.
Associate Professor of Chemistry, Harvard University
E Bright Wilson
First Edition
Twelfth Impression
McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK AND LONDON
1935

Introduction to Quantum Mechanics (First Edition, 1935, McGraw-Hill Book Co.), endorsed by Linus Pauling and E. Bright Wilson; the book is owned by Dudley Herschbach.

On to Harvard

The quality of his work won Bright election in 1934 to the Society of Fellows at Harvard as one of a half-dozen Junior Fellows chosen annually for a three-year term. The Society had been founded about a year earlier by A. Lawrence Lowell, then-President of Harvard, stimulated by his close friend L. J. Henderson, Professor of Biochemistry and urbane Boston Brahmin. As the first chairman of the Senior Fellows of the Society, Henderson dedicated much effort to bringing to Harvard the spirit and the mores of a Senior Common Room of the old English colleges. The concept included Monday evening dinners that the Junior Fellows were expected to attend, about the only formal requirement of their Fellowship. Gourmet meals served with choice wines provided the backdrop to lofty conversations presided over by Henderson. In the Society as in later life, Bright remained quite uncorrupted by elitism.

His Junior Fellowship was very fruitful, as he developed quantitative treatments of the dynamics of molecular motions and carried further his work on symmetry analysis. In reminiscence, Bright said "I had three years to show what I could do…I soon found that there were people around who would not tell me what to do but who were extraordinarily helpful when I wanted help." George Kistiakowsky had moved from Princeton to Harvard while Bright had been at Caltech. Kisty was obviously the choice to revitalize Harvard chemistry, brought in by the new president, J. B. Conant, himself an outstanding organic chemist. In physics, J. H. Van Vleck was a great help to Bright, with a "perplexing flow of mixed wave mechanical, operator calculus, and matrix language which often baffled this narrowly Schrodinger-equation-oriented neophyte. I had to learn to look at things in these alternate languages."

The Harvard Chemistry Department acted with alacrity to appoint Bright as an Assistant Professor in 1936. He gladly taught courses, giving up the third year of his Junior Fellowship. He took over the teaching of the undergraduate course in physical chemistry and also gave courses on quantum mechanics and other advanced theoretical topics for graduate students. In response to his outstanding performance, he was promoted to an Associate Professor with tenure only three years later at the early age of 30.

Bright was fully devoted to teaching in all its aspects. A characteristic instance was told to me by Don Hornig. As a sophomore in 1937, he took Bright's physical chemistry course. In those days, the course dealt largely with thermodynamics, but Don had discovered the recently published text on Quantum Mechanics by Pauling and Wilson. When Don asked Bright for help with one of the problems in the book, Bright volunteered to meet with Don on Saturday mornings and kept up this informal tutorial regime for much of the academic year. Bright was then only in his second year in the faculty, untenured, teaching two courses, and intensely involved in research. This episode says much about his attitude to teaching, and also about his keen judgment, for Don was destined to become one of the most distinguished of Bright's students.

Bright recalled that the period 1934-41 "was extremely exciting for me." With Harold Gershinowitz, he constructed an automatic infrared spectrometer that his students used to measure vibrational absorption spectra of a number of theoretically important molecules. His group also

> *carried out normal coordinate analyses, calculations on vibrational heat capacity, applications of group theory, plus developments in the theory of rotation, vibration, centrifugal distortion, Coriolis coupling, barriers to internal rotation, different forms for the secular equation of vibration.... Theory was mixed with experiment and we benefited much from close collaboration with Kistiakowsky and his group.*

On to Explosives for War

This intense scholarly activity was interrupted by World War II. After the formation of the National Defense Research Committee (NDRC) in the summer of 1940, Kisty "found it easy to interest Bright in military work on explosives." With several students he undertook the study of shock waves in water. His progress was handicapped by the lack of suitable pressure sensors, so he had to develop those and suitable electronics from scratch. Bright also directed efforts to develop piezoelectric pressure gauges for shocks in air. Small-scale explosions were regularly set off across the Charles River in the open fields near the Harvard School of Business Administration. Fortunately, in early 1942 an Underwater Explosives Research Laboratory (UERL) was organized. This was led by Bright and hosted at the Woods Hole Oceanographic Institution.

In the early years of the NDRC, representatives of the military services (as well as the explosives industry) had attitudes toward to academic scientists ranging from benign tolerance to outright antagonism. Yet Bright succeeded in attaining good relations with the Navy Bureau of Ordinance. The Navy realized that UERL had unique techniques for measuring explosions under water. The continued decimation of allied shipping by Nazi U-boats led to increasing demands on UERL to evaluate the perforce of depth charges and other anti-submarine munitions. This meant testing in deep waters miles from shore, so the laboratory acquired an old fishing schooner, the *Reliance*. She was outfitted as a floating laboratory to record the electronic signals from large recoverable rigs towed behind the vessel. The rigs held the explosive charges and sensors deep under water. The work had to be done in winter as well as summer, so the scientists had to be tough mariners.

Kisty related a favorite story that "even Bright's gentleness seemed to depart at times. One day at sea, he saw a novice test crew member connecting an ohmmeter as if to test the continuity of the hair-fine bridge wire of the electric detonator already inserted in the 500-lb depth charge hanging overboard. With seconds at his disposal before the lethal bang, Bright in one smooth motion reached for an oar and laid flat the innocent beginner." Kisty also on occasion would tease Bright about the wicked pleasure he used to take in escorting certain visiting dignitaries on the Reliance into open water, "in the foulest weather, to demonstrates this or that new twist in test technology while his cold and drenched audience wallowed in choppy seas."

During the five years of war work, Bright made many significant contributions, both practical and theoretical, and gathered a strong and dedicated group of collaborators.

The harmonious symbiosis of the UERL and its host, the Woods Hole Oceanographic Institution, induced Bright later to accept election to the governing body of the Institution. He helped to guide it over the years of expansion of oceanographic exploration and research.

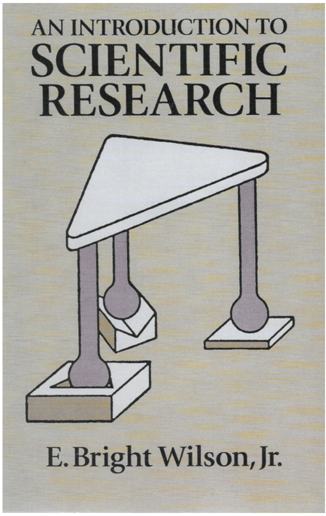
Return to Harvard and Spectroscopy

On his return to Harvard soon after the war's end, Bright resumed teaching and, as in later years, offered several different courses, both undergraduate and graduate. He also became heavily involved in the administrative affairs of the chemistry department, but even such chores did not prevent him from resuming research with earnest vigor. Bright found the department "swamped with ex-soldiers and ex-war researchers seeking Ph.D.s.…[S]oon I had 13 students, a peak. We also offered extra refresher sources for them in undergraduate-level subjects, which required [faculty to] do a lot self-refreshing before we dared to lecture."

In 1946, Bright teamed again with A. Judson Wells, who back in 1941 was the first of Bright's research students to obtain his Ph.D. Post-war, they resolved a long-standing disagreement between absolute infrared intensity data and the contributions of infrared bands to the total molecular polarizability. Their method, which exploited pressure broadening of spectral lines, became widely used and yielded much information on the charge distributions within molecules.

Impressed by the wartime development of radar, Bright pursued microwave spectroscopy to study molecular rotational transitions. In 1947, after a year Richard Hughes and Bright invented and built a Stark-effect microwave spectrometer. It became the most widely used instrument for this field. The key feature was employing Stark-effect modulation. Tuning the detector circuitry to the modulation frequency greatly enhanced the signal-to-noise ratio, made the output signal virtually insensitive to random power fluctuations, and enabled the amplifiers to work at a convenient radio frequency. The introduction of modulation increased the sensitivity of the spectrometer by more than three orders of magnitude. Thereby wide classes of polyatomic molecules were accessible, rather than just linear rotors and symmetric rotors. With the Stark spectrometer, Bright's group and others undertook systematic studies of the myriad rotational transitions of asymmetric rotors and attained detailed data on molecular configurations, dipole moments, quadruple coupling constants, centrifugal distortion, line broadening, and other phenomena.

Much of what become standard working methodology in spectroscopy is derived from such original research. In retrospect, Bright liked to stress that the Stark modulation was "a very obvious and in fact a quite trivial way of doing the job…but most others in the field were trying much more sophisticated and complicated schemes." During the war, most worked on radar and so were very knowledgeable about the microwave field. In all of Bright's work, there is strong coupling between theoretical developments and experiments, with emphasis on providing general methods. This was exemplified by his extension of the same group theory methods he used for molecular vibrations to spin-spin interactions in nuclear magnetic resonance and other aspects of molecular dynamics.



An Introduction to Scientific Research, E. Bright Wilson, Jr. The first edition came from McGraw-Hill Book Co, 1952); this cover is from Dover Publications, 1990.

In 1949-1950, Bright took a sabbatical in Oxford, United Kingdom, as a Guggenheim Fellow and Fulbright Grantee at Oxford University. He considered it a very "important break" in his career. Mainly he worked on a book, *Introduction to Scientific Research*. Published in 1952 and still in print, it is unabashedly evangelical about methods of operational research, design of experiments and apparatus, analysis of experimental data, errors of measurement, treating mathematical computations, and reporting and publishing results of research. The book has much wise, practical advice and many whimsical stories. For instance, the index lists: Gremlins 128; Haircut story, 266; Savage love nest story, 9; Three chickens story, 46; Tobacco juice story, 128, and many more.

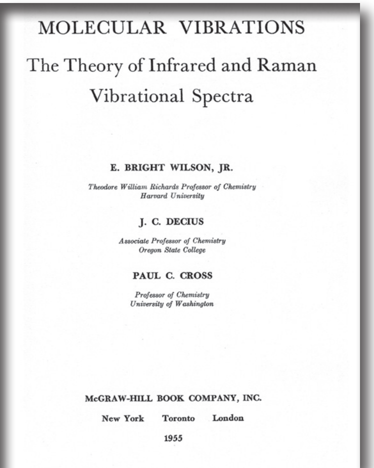
His was the first year of the Fulbright Scholarship program, and Bright was royally treated by the British. He gave "something like 35 lectures all over the United Kingdom, mostly on microwave spectroscopy."

Another Service Episode

In 1952-53, Bright's scientific odyssey was again interrupted. The Korean War was seesawing and the Cold War with the Soviet Union was quivering. Howard P. Robertson, an outstanding physicist known to Bright via Princeton and Caltech, persuaded Bright to take his place as Research Director and Deputy Director of the Weapons Evaluation Group (WSEG) at the Pentagon in Washington, D.C. This was an operations analysis outfit working for the Joint Chiefs of Staff and the Secretary of Defense. Bright described it as "made up of military officers, mostly colonels or Navy captains, plus a pitifully small group of civilian scientists." Kisty described it as "faltering at the time and only the heroic efforts of Bright changed it into an adequately functioning organization." He stayed only eighteen months, as it "was a period of great stress for me; I was not built for that kind of life." In the mid-1960s, however, Bright again began accepting assignments in Washington when he believed he could make a contribution. Along with Kisty and others, he tried in vain to stop the futility of the Vietnam War.

Molecular Vibrations and Internal Rotations

In 1955 Bright brought out a book, *Molecular Vibrations*, that he and his co-authors, J. C. Decius and P. C. Cross had labored with for many years. It was heartily welcomed. The purpose was to develop essential elements of theory to understand and utilize the infrared and Raman spectra of polyatomic molecules. It started from "the simplest form and advancing to fairly elaborate and powerful theorems useful in more complicated applications." Chapters are arranged as spectral lines can be assigned by use of symmetry considerations and selection rules. Other chapters treat isotope effects or calculation of force constants. Thousands of research papers emerged to employ Bright's "FG matrix method" for analysis of normal modes of vibration.


MOLECULAR VIBRATIONS

The Theory of Infrared and Raman Vibrational Spectra

E. BRIGHT WILSON, JR.

Theodore William Richards Professor of Chemistry
Harvard University

J. C. DECIUS

Associate Professor of Chemistry
Oregon State College

PAUL C. CROSS

Professor of Chemistry
University of Washington

McGRAW-HILL BOOK COMPANY, INC.

New York Toronto London

1955

Molecular Vibrations, The Theory of Infrared and Raman Vibrational Spectra, E. Bright Wilson, Jr., J.C. Decius, Paul C. Cross (1955, Mc- Graw-Hill Book Co.)

An exciting time in Bright's research group also emerged in 1955 in their use of microwave spectroscopy to determine barriers to internal rotation about single bonds in molecules. Internal rotation has considerable importance: it permits the coiling and uncoiling of protein molecules and other polymers. Usually such internal rotation is not free, but it is hindered by a potential energy barrier. Bright's interest in the barrier was aroused in the late 1930s by Kisty's thermodynamic data on ethane, H_3C-CH_3. Also, Bright with Bryce Crawford in 1941 developed a theory involving vibrations with torsional motions of molecules with methyl groups. Microwave spectroscopy made it feasible to study the lower torsional states directly, as the internal motion perturbs the rotational spectrum. The first example using microwave spectra to determine a potential barrier came with methyl alcohol in 1951 in work by

D. G. Burkhard and David M. Dennison at the University of Michigan. Bright's team and others made rapid progress; by 1959 the barriers had been obtained for twenty-five molecules containing a methyl group.

Microwave spectroscopy evaluates the barrier heights by resolving quantum tunneling. If the barrier for internal rotation of a methyl group is high, then essentially there are only small-amplitude torsional oscillations in three separate potential wells. If the barrier is low enough, however, tunneling between the wells occurs and causes the microwave rotational transitions to split to doublets. These splittings are extremely sensitive to the barrier height. If the barrier is too high for splitting a rotational transition, it comes from the ground torsional level. Fortunately, satellite transitions that obtain splitting can be found from the first excited torsional level, at which the barrier height is lower. Gratifying theory evolved to treat hindered internal rotation using standard techniques and tables employed for ordinary "rigid" asymmetric rotor molecules.

Along with obtaining barrier heights, microwave spectra can provide the possible conformation of a molecule that corresponds to the potential minimum. For molecules with a methyl group, its orientation has been determined by CH_2D or CHD_2 isotopic species. Thereby, the minimum staggered conformation has been established as the stable one for ethane, methyl silane, and some halogenated derivatives. For acetaldehyde, acetyl fluoride, and acetyl chloride the oxygen atom of the acetyl group is eclipsed by one of the methyl hydrogens. For propylene, one of the methyl hydrogens is eclipsed with the double bond, so that the other two methyl hydrogens are staggered by the hydrogen of the CH_3 group.

Most of the data for potential barriers and equilibrium orientations were obtained from Bright's team. He collected the results and examined the electronic properties involving the origin of the barriers. He concluded, at least when a methyl group is involved, that the barrier "must in some way be an inherent property of the axial bond itself and not due to the electron distribution out on the attached bond any considerable distance." Pauling quickly developed a simple theory that "the potential barriers are not a property of the axial bond itself…but result from the interaction of adjacent hybrid bond orbitals with a small amount of f character." In 1963, a major calculation of the barrier to internal rotation in ethane was done by Russell Pitzer and William Lipscomb. Their agreement (3.3 kcal/mol) was good with experiment; it indicated that d and f orbitals did not make an important contribution. Bright was amused because Lipscomb likewise had had Linus as his mentor. Russell was the son of Kenneth Pitzer, who had in 1936 discovered the ethane barrier by thermodynamic means.

In 1995, the methyl group orientation of propylene was key in a triumphal stereospecific synthesis by Yoshito Kishi of palytoxin, $C_{129}H_{223}N_3O_{54}$. There are twofold conformational choices at 72 sites, hence $2^{72} = 5 \times 10^{21}$ stereoisomeric structures. The wizardry of Kishi and his team enabled them to synthesize with virtually 100 percent yield the particular stereoisomer that is biologically active (as a fearsome neurotoxin). An essential feature of Kishi's synthetic strategy he learned from Bright's students about the propylene configuration of an sp^3 carbon atom adjacent to an sp^2 carbon.

Theoretical Quantum Electronic Chemistry

In 1964, Bright had a sabbatical leave in Paris, enjoying the hospitality of Raymond Daudel at his Quantum Chemistry Institute. That year, Bright recalled that he decided to "change my policy and take on some purely theoretical students." He worked up "several projects that seemed promising and offered them to students." Returning again to Harvard, he had "phenomenal luck of signing up…several pure theorists, besides a very able group of experimentalists." Among the theory projects in 1967, Shirley Seung and Bright treated the ground-state energy of lithium and three-electron ions. Good accuracy was attained with perturbation theory using the entire interelectron repulsion potential. It harked back more than thirty years to Bright's Ph.D. thesis! In a major project, Frank Weinhold and Bright dealt with reduced-density matrices of atoms and molecules and mapping out general necessary conditions for N-representability. In a different style, Bright with P. S. C. Wang delivered correlation diagrams using exact wavefunctions analogous to the orbital symmetry of Robert Woodward and Roald Hoffmann for classifying concerted chemical reactions. Bright liked the description in terms of natural orbitals, as it had "aesthetic advantage" and was "capable of future improvement."

Other theoretical projects were useful with electronic structure and other areas. Phillip Jennings and Bright developed methods of error bounds for eigenvalues. Likewise, Carey Rosenthal with Bright worked out upper and lower bounds, illustrated with electronic structure. Two notable members in Bright's batch of pure theorists, Billy Miller and Bill Reinhardt, did excellent Ph.D. theses and published solo papers. They treated gas-phase intimate molecular dynamics of individual reactive collisions, inspired by the blossoming development of molecular beam experiments in other research groups.

Two theory papers dealing with electrons were published solo by Bright. In "Symmetry, nodal surfaces, and energy ordering of molecular orbitals" (1975), he explored relationships between the geometrical symmetry and the nodal surfaces of molecular orbitals. The minimum numbers of nodal regions for orbitals for the principal point groups were tabulated. As an example, Bright used benzene, just as he did forty years earlier at Caltech. In the second paper, "Fifty years of quantum chemistry" (1976), Bright assessed influences such as "psychological satisfaction" and "predictive theories." He discussed MO orbitals, the two-particle reduced matrix, and the uneven Hartree-Fock method as well as the valence bond method. He predicted that "capabilities…will be more notably more impressive in the near future."

Double Resonance and Hydrogen Bonding

In 1965, Bright's group undertook another new domain, dealing with experiments of energy transfer in rotationally molecular inelastic collisions, rather than molecular structure or reactions. The energy transfer was opened up by a fresh technique, microwave double resonance. High microwave power is used to "saturate" a rotational absorption line. This causes the populations of the two specific molecular rotational energy levels connected by the transition (the "pump" levels) to approach equality. The other rotational levels then readjust their populations through collisions with the molecules in the pumped levels. The altered populations of other levels are monitored by absorption of microwaves at frequencies of other rotational lines of the molecule. By modulating the pumping power, Bright demonstrated how to provide a time scale by which the effects of successive collisions can be separated from those single collisions. Again, the method was almost embarrassingly fruitful and stimulated important theoretical work on rotational energy transfer in collisions.

In 1970, Bright began using low-resolution microwave spectroscopy to study intramolecular hydrogen bonds. The H-bond links two parts of a single molecule and thereby closes a ring. His group observed many sizeable H-bonded bimolecular complexes and thereby furnished useful approximate structural information. Bright provided in 1975 a collection of H-bonded complexes of carboxylic acids, and in 1987, his last paper, reviewed a wide variety of bimolecules and the kinds of data obtainable from microwave spectra.

Onward as Emeritus Professor

In 1979, his retirement and naming as emeritus professor was celebrated by a special issue of *JPC*. The leading paper was about Bright's inspiring career, described by Kistiakowsky (akin to a *JPC* issue in 1971 in which Bright wrote about Kisty's career). Included were lists of Bright's awards, his publications, a roster of students mentored by Bright who obtained Ph.D. degrees, and a comparable list of research associates: postdoctoral fellows, guests, and master's and undergraduate students. Many Wilson alumni had spread over the world and about eighty of them worked in academic institutions.

Also in 1979, Bright was invited to write a prefatory chapter on molecular spectroscopy in the *Annual Review of Physical Chemistry.* He delivered a major review of "the amazing proliferation of new techniques, capabilities, and applications." He stressed that the arrival of lasers bought "coherence effects that play an important role across most of the frequency domain." Bright was also invited in 1979 to a celebration of the 100th birthday of Alert Einstein at the *International Journal of Quantum Chemistry's* Quantum Chemistry Symposium (IJQC-QCS). There he gave a talk and produced an article, "Einstein and Quantum Mechanics," wherein he considered Einstein "after so much to bring about its birth he disowned the child on philosophical grounds." Bright gave another paper, "On the Definition of Molecular Structure in Quantum Mechanics," wherein he dealt with both engineering and philosophy.

In 1980, Bright was celebrated again by IJQC-QCS; the roster lists from *JPC* were included, but this time he gave a major paper: "Some Personal Scientific Reminiscences." He expanded upon it in a two-day interview in 1986 that was recorded and made available in a transcript by the Chemical Heritage Foundation (now the Science History Institute).

Family Life

Along with his intense professional activities, Bright enjoyed a vigorous and happy family life. When he arrived at Harvard, he soon met and married Emily Buckingham in 1935 Emily was a Radcliffe student, stayed on for a master's degree in physics, and taught at Wellesley. They had three children: Kenneth, David, and Nina, born 1936, 1940, and 1942, respectively. The family eagerly did outdoor sports, especially skiing, hiking, and canoeing in folding canvas boats. Sadly, in early 1954, Emily died from a sudden illness; it was found to be leukemia. Bright had to cope with her tragic loss, helping their children, then 18, 14, and 12 years old. He was also serving as the chairman of the Harvard Chemistry Department.

Bright and Thérèse at their wedding, 1955.

Before long, Bright discovered a remarkable mate. Thérèse Bremer came to Harvard in 1954 as a postdoctoral fellow, working in Kistiakowsky's laboratory. Her home was in Brussels, Belgium, where her father was a professor of physiology, and she had already done outstanding research in photochemistry that had won her a Fulbright fellowship. Kisty had left on a sabbatical in February 1955, but stories reached him "about a sudden burst of social activities between the Wilson research group and mine.…My research students passed on tales about canoe parties and weekend telephone calls from Bright requesting one of his students…to run over and fill the liquid nitrogen traps in Dr. Bremer's apparatus." Soon Bright and Thérèse were married and brought forth three more adventurous youngsters: Anne, Paul, and Steven. Kisty was delighted "to witness over the years how her vivacity and wit have kept Bright constantly on his toes in attempts to maintain some dignity."

Mentor and Fine Colleague

Bright served as mentor to ninety Ph.D. students and about sixty postdoctoral fellows. Some 400 papers were published from his lab. He was the sole author for sixty-five of them. He was a co-author for about ninety papers. Unless he had a major contribution, Bright insisted that he would not include his name. Professors of chemistry worldwide usually put their names on every paper from their lab. Bright felt that his job was to help the members of his lab gain recognition for their own work. This was part of his character, generous and scrupulous honesty. Moreover, Bright had Linus Pauling as a unique mentor. During his three years at Caltech, Bright published ten solo papers. Linus and Bright were co-authors only in writing their canonical textbook on quantum mechanics.

Research students from other groups and undergraduates as well as faculty at Harvard and elsewhere all naturally sought out his advice and help. His efforts to foster the careers of young people were acknowledged in two ways that probably pleased him as much as the many awards and honorary degrees he received. First, the Chemistry Department baseball team had long called itself the "E. Bright Stars" and enjoyed presenting "EB" with their monogrammed shirts and caps.

Second, in 1982 his students and colleagues endowed the Wilson Prize Lectureship, given each year to a young chemist of outstanding promise. There is no restriction as to subfield, although the criteria were stretched for the inaugural award. Bright's eldest son Kenneth was invited to talk of his work in theoretical physics and the lecture scheduled for mid-December, near Bright's birthday. But the event had to be postponed because Kenneth and the whole Wilson clan took an unanticipated trip to Stockholm, for Kenneth to receive the Nobel Prize in Physics. The inaugural Wilson Lecture was appropriately rescheduled for Valentine's Day. In his talk, Kenneth said that his dad sparked his success: "It was like, if you wanted to go into baseball, growing up with Babe Ruth."

Bright and his son Kenneth at the Nobel dinner, December 10, 1982.

Kenneth's remarkable work used a renormalization group to break down a large problem into a series of smaller steps. His was a new calculus that could treat a wide range of problems.

In 1994 the American Chemical Society (ACS) established the E. Bright Wilson Award in Spectroscopy. For twenty years, the award was funded partly from ACS and various industrial sources. Then industrial sources dried up. In 2016, Bright's past students, post-docs, colleagues, and previous awardees, contributed an enduring endowment for the award.

In his final years, Bright suffered miserably from Parkinson's disease, but he never offered a single word of self-pity or complaint. To the end, he remained earnestly engaged with his beloved science, his colleagues and family, and his university and nation. He had a wonderful career and humanity. A fitting tribute to him comes from the book on thermodynamics that excited Bright at age fifteen. The grand opening sentences are: "There are ancient cathedrals which, apart from their consecrated purpose, inspire solemnity and awe." There are people who inspire us to strive for lofty ideals. E. Bright Wilson was such a one.

HONORS

1937	Award in Pure Chemistry, American Chemical Society (ACS)
1948	Medal for Merit, United States Government
1962	Debye Award in Physical Chemistry, ACS
1966	Alumni Distinguished Service Award, Caltech
	James F. Norris Award in Teaching of Chemistry, Northeast Section, ACS
1972	Linus Pauling Award, Oregon and Puget Sound Section, ACS
1973	Rumford Medal, American Academy of Arts and Sciences
1975	Free University of Brussels, Honorary D.Sc. degree (honoris causa)
1976	National Medal of Science
	Antonio Feltrinelli Award, Rome, Accademia Nazionale dei Lincei
	Dickinson College, Honorary D.Sc. degree (honoris causa)
	University of Bologna, Honorary D.Sc. degree (honoris causa)
1977	Monie A. Ferst Award, Sigma Xi
1978	Pittsburgh Spectroscopy Award
1978	T.W. Medal, Northeast Section, ACS
1978	Robert A. Welch Award
1978	Earl A. Plyler Award, American Physical Award
1979	Josiah Willard Gibbs Award, Chicago Section, ACS
1979	Ellis R. Lippincott Award, by Coblentz Society
	Columbia University, Honorary D.Sc. degree (honoris causa)
1981	Princeton University, Honorary D.Sc. degree (honoris causa)
1982	Harvard University, Honorary D.Sc. degree (honoris causa)

APPENDIX

Kenneth Geddes Wilson

His biography and Nobel lecture: "The Renormalization Group and Critical Phenomena," are readily obtained on the web. Wilson died from lymphoma on June 15, 2013, aged 77.

Thérèse Bremer Wilson

Dudley Herschbach and his wife Georgene loved Thérèse (1925-2014). We cherished her warm-hearted, earnest friendship, her quick wit, her sparkling laugh. Also, often her wise counsel, keen insights, and on occasion her well-directed bursts of indignation. For about thirty years, we enjoyed many lovely times with Thérèse and Bright, often swapping exploits of our children. After Bright died in 1992, we visited often with Thérèse, usually for tea at her Cambridge apartment. Sometimes we met Anne or Paul or Steven or one or more of her grandkids. It was a joy to witness the pride and love they shared with each other. During her last year, Thérèse was happy and proud with the publication of her book *Bioluminescence* that she wrote with J. Woodland Hastings. Beautiful and fascinating, the book excites awe for Nature's wonders and admiration for the devotion of scientists striving to elucidate those marvels. Thérèse gave the book a glowing subtitle: *Living Lights, Lights for Living*.

When her health declined, Thérèse was undaunted. She decided not to have further medical interventions, saying "I don't want to be greedy. My life has been wonderful, filled with my marvelous family, close friends and much happiness." She died peacefully at home on April 28, 2014.

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This memoir is drawn chiefly from accounts published by Bright and by the author with some other articles by colleagues listed below.

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