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GEORGE CLAUDE PIMENTEL
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A Biographical Memoir by

C. BRADLEY MOORE

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Biographical Memoir

George C. Pimentel

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BY C. BRADLEY MOORE

George Pimentel was an intense man with a contagious enthusiasm for science, teaching, sports, and all things new and challenging. He was a master of empirical physical models. Pimentel was always looking for the biggest challenges and for truly new phenomena. He was not easily discouraged. When a small spot on his retina kept him from becoming one of the first scientist astronauts, he built a new kind of infrared spectrometer to go look at Mars. In every aspect of his professional life he attacked the big problems head on, and yet at the personal level he always made time to bring along a student or help a friend. He was an enthusiastic and competitive sportsman. His level of exertion and commitment was at least the maximum possible in everything that he did.

George Pimentel's research has had a profound effect on chemistry.[1] The common thread of his research was a desire to understand unusual chemical bonding situations and their consequences for structure and chemical reactivity. The information he obtained on marginal species, on chemical reactions, and on photochemical processes is a key part of the base upon which our understanding of chemical reactions and molecular structure is founded. His fearless approach to exploiting new technology and developing new techniques led to pioneering work in hydrogen bonding (1960,2) and in the structure, bonding, and reactivity of free radicals and other highly reactive molecules (1956; 1960,1; 1963; 1964,2), to the creation of chemical lasers (1964,1; 1965,2; 1967), and to the infrared spectroscopy of the atmosphere and surface of Mars (1969; 1970,1,2; 1974). Pimentel pioneered the spectroscopy of molecules in solid rare gases and other inert matrices beginning in 1954. He observed the first spectra of several free radicals and of many species with unusual bonding (see Table 1). He has provided examples of selectivity for chemical reactions in matrices initiated by infrared excitation of single normal modes (Pimentel, 1958a; 1960,4; 1985,2).

There are few chemists or biochemists who have not benefited from Pimentel's early work (1954, 1957) and his authoritative book (1960,2) on the hydrogen bond. His matrix isolation techniques for trapping reactive molecules in solid rare gases or nitrogen are now used routinely in most chemical research laboratories in the world (1956, 1957, 1960,1). Pimentel pioneered the use of high-speed IR detectors in spectroscopy (1965,1). Few had the courage to copy the spinning grating and fast detectors of his rapid scan infrared spectrometer that extended flash photolysis into the infrared and yielded the reaction kinetics and vibrational spectra of free radicals as well as the discovery of the first chemical lasers (1964,1; 1965,1,2). In the process of developing the chemical laser he exploited it to produce a new level of understanding of energy release to the vibrations and rotations of reaction product molecules (1970,3; 1972; 1973; 1984). The next generation of this spectrometer incorporated a spinning filter wheel, a light-weight body, and a telescope and became the Mariner Mars IR spectrometer (1969; 1970,1,2; 1974). The spectra of Mars yielded concentrations of molecules in the Martian atmosphere, the Martian surface composition, and the topography of Mars (1969; 1970,1,2; 1974).

All in all, Pimentel is exceptionally highly regarded by chemists and spectroscopists for his creativity and insight, for his clear physical models, for his consistent record of opening new fields of great significance to chemistry, and for the care and thoroughness that made his work so eminently reliable.

Pimentel's truly outstanding contributions to science go well beyond his published research to include education from high school through graduate school, university and government service, and leadership in professional societies. He mentored 70 Ph.D. students[1] including 4 who are already members of the National Academy of Sciences and one Nobel laureate. An additional 60 people were postdoc, M.S., or undergraduate members of Pimentel's research group. His research students learned to strive for quality and perfection. His demanding standards; his critical, sharp physical insight; and his energetic enthusiasm in discussing the interpretation of new results inspired many. Pimentel's CHEM Study text (1960,3) introduced a generation of Americans to the excitement of work in science as well as to the basic facts of chemistry. Pimentel taught freshman chemistry to many thousands of students. His course was legendary; he taught with great enthusiasm even through the painful, terminal stages of his colon cancer.

Pimentel won one of Berkeley's distinguished teaching awards (1968) and several national teaching awards. The American Chemical Society's Award for Chemical Education was named the Pimentel Award in his honor; Berkeley's Physical Sciences Lecture Hall became Pimentel Hall in 1994. Pimentel served the nation and the scientific community as deputy director of the National Science Foundation from 1977 to 1980. Upon returning to Berkeley he became an associate director of the Lawrence Berkeley National Laboratory (LBNL) and head of the Laboratory for Chemical Biodynamics, an organized research unit of the College of Chemistry and a division of LBNL. As president of the American Chemical Society for 1986[2] he created National Chemistry Day and National Chemistry Week. His leadership served the profession and the science of chemistry. George Pimentel presented science with eloquence and distinction to our legislators and government executives. Pimentel's National Research Council report, *Opportunities in Chemistry* (1985,1), focused much attention on chemistry in Washington and around the world. Throughout his lively career he was an innovative leader on the Berkeley campus and one of Berkeley's most outstanding classroom teachers. Pimentel's papers are archived for scholars at Berkeley's Bancroft Library, University of California.

George Pimentel was born to French parents near Fresno, in central California. His family moved during the depression to a poor section of Los Angeles, where his parents separated. The children were thereafter supported by their mother. During an interview in the mid-1970s[3] George recounted:

> My father reached only the third grade and my mother was taken out of high school so that she could attend a business school. So their influence did not come through their own educations, but rather through the high value they placed on education. They were very enthusiastic about the academic successes of my brother and me. . . I also gained encouragement from my brother who was only a year and a half older than I, a very bright person. He offered intellectual companionship, guidance, and encouragement to me as the younger brother. We were very close. He was excellent in mathematics and I tried to emulate him in that, as in everything else. . . My father was in construction work, working as a foreman, working with his hands. That led me to contemplate going in that same direction, only in a professional way—trying to realize my father's ambitions that were out of his reach because he didn't have an education. And so my initial expecta-

tion when I got out of high school was that I'd become a civil engineer. . . I have one additional small experience that may have stimulated my interest in science. I attended junior high school in northern Los Angeles and this put me within bicycling distance of Cal Tech. During this time, I occasionally rode my bicycle over to Cal Tech at night to hear popularized lectures on science by Robert Millikan. I found these very exciting.

In 1939 Pimentel began to work his way through the University of California, Los Angeles; his interests shifted from civil to chemical engineering and then to physical chemistry and undergraduate research with J. B. Ramsey. He graduated in 1943 (and received the UCLA Distinguished Alumnus Award in 1979). For his first job he went north to join the Manhattan Project in Berkeley, where he worked on chemical processes for the separation of plutonium with Professor Wendell M. Latimer. In 1944 when he grasped the full implications of the project, however, he enlisted in the Navy and volunteered for submarine duty to do his part in hastening the war's end. At the end of the war he played an important role in establishing the U.S. Office of Naval Research, the beginning of today's government funding for science in universities.

In 1946 he returned to Berkeley for graduate work in infrared spectroscopy with Kenneth Pitzer. Upon earning his Ph.D. in 1949 he joined the Berkeley faculty as an instructor and became an assistant professor in 1951. He remained an active Berkeley faculty member until his death. Pitzer had also joined the Berkeley faculty immediately upon earning his Berkeley Ph.D. with Latimer, who had done likewise following graduate work at Berkeley with Gibson. Thus Pimentel and Pitzer stand as counter examples to the usual wisdom regarding faculty inbreeding. His transition from an impoverished working-class and service background to international fame makes the quintessential American dream a reality.

Pimentel's intense loyalty to the University of California and to chemistry were grounded in the opportunities they afforded him to transform his life and his mind. The Pimentel Memorial Lectureship endowed by IBM and a research award to a graduating senior recognize annually Pimentel's contributions at Berkeley.

INFRARED SPECTROSCOPY, HYDROGEN BONDING, FREE RADICALS, AND MATRIX ISOLATION

Pimentel's publications from his graduate work and his first years on the Berkeley faculty were primarily on the infrared spectroscopy of gases, solutions, and crystals of boranes and hydrocarbons, especially cyclic hydrocarbons. His lifelong interest in unusual chemical bonding is apparent in his first few years on the Berkeley faculty. In 1954 his first papers on the IR spectra of hydrogen-bonded molecules (1954) and on the matrix isolation technique appeared. In the following years he focused on the IR spectra of hydrogen-bonded species (1960,2) of free radicals produced by UV photolysis (see Table 1) and of highly reactive molecules usually isolated in solid rare gas or nitrogen matrices at between 4K and 20K. Pimentel developed the matrix isolation method to permit leisurely infrared spectroscopic study of such species. Fortunately, matrix shifts of infrared bands are quite small, facilitating identification relative to gas phase prototypes. Furthermore, the features are extremely sharp, enhancing sensitivity and resolution of closely spaced lines. Thus, vibrational spectra could be reliably assigned and conclusions drawn regarding the bonding. The first matrix studies were begun by Whittle and Pimentel before 1954, but prototype experiments were successful only after a sustained period of development of reliable low-temperature cells and systematic investigation of the effects of concentration, deposition conditions and temperature upon isolation efficiency, and deposition rate (Becker and Pimentel, 1956; Becker et al., 1957; Van Thiel et al., 1957; Pimentel, 1958a,b; Goldfarb and Pimentel, 1960). Finally, in 1958 this effort was rewarded by the first infrared detection of the molecule HNO (Brown and Pimentel, 1958), soon followed by the detection of HCO (1960,1). Since that time the method has come into full flower; in the 1961-1965 period some 30 diatomic and triatomic transient species were recorded with the matrix method while in the subsequent five-year period the number rose to about 70. Among the transient and unusual molecules first detected in the Berkeley laboratories are those shown in Table 1 (p.10).

Today the infrared spectra of hundreds of free radicals and transient molecules are known through the application of the matrix isolation technique and probably more than three-quarters of these were detected in the Berkeley laboratories or by former Pimentel students. Pimentel also studied many hydrogen-bonded systems in matrices and in 1960 published *The Hydrogen Bond* with McClellan (1960,2), a classic for decades. Many organic and inorganic chemists around the world now routinely study reactive molecules by matrix isolation spectroscopy throughout the UV, VIS, and IR. Most of Pimentel's studies were carried out at 15K to 20K using one to two liters of liquid hydrogen. The apparatus was placed under a large hood with heavy, friable asbestos curtains that covered the hair and clothing of the experimenter. Experiments often lasted several days and involved hot mercury lamps, tired students, many kilograms of mercury inside fragile glass vacuum systems, and other hazards. Thanks to Pimentel's emphasis on safety, hydrogen flames were seen only twice and there were no serious accidents. Free radicals trapped in inert matrices display chemiluminescence on warming to a diffusion temperature. Spectral analysis of this cryogenic chemiluminescence shows the role of excited electronic states in highly exothermic reactions.

TABLE 1 SPECIES OBSERVED BY MATRIX ISOLATION

MOLECULE	REFERENCE
HNO	Brown and Pimentel, 1958
HCO	1960,1
N (thermoluminescence)	Brocklehurst and Pimentel, 1962
O = C = N H + O	Milligan et al., 1962
KrF_2	1963
N_2H_2	Rosengren and Pimentel, 1965
NH	Rosengren and Pimentel, 1965
LiON	Andrews and Pimentel, 1966
FO_2	Spratley et al., 1966; Noble and Pimentel, 1966
CH_3	Andrews and Pimentel, 1967b
CH_3LiCl	Tan and Pimentel, 1968
Cl-ClO	Rochkind and Pimentel, 1967
$(ClO)_2$	Rochkind and Pimentel, 1967; Alcock and Pimentel, 1968
Li	Andrews and Pimentel, 1967a
$XeCl_2$	Nelson and Pimentel, 1967a
Cl_3 (or Cl_3^-)	Nelson and Pimentel, 1967b
HOF	Noble and Pimentel, 1968a
HCl_2 (or HCl_2^-)	Noble and Pimentel, 1968b
Cl_xBr_y	Nelson and Pimentel, 1968
HBr_2 (or HBr_2^-)	Bondybey et al., 1971
iso N_2O_3	Varetti and Pimentel, 1971
H	Bondybey and Pimentel, 1972
NH_3HCl complex	Ault and Pimentel, 1973
^{15}N-PAN	Varetti and Pimentel, 1974
NH_3-LiCl complexes	Ault and Pimentel, 1975

Such studies have revealed previously unobserved electronic states and recombination on electronic hypersurfaces for SO_2*, SO*, S_2*, CO_2*, HCOOH*, C_2H_4*, and BaO* (Long and Pimentel, 1977; Lee and Pimentel, 1978; Fournier et al., 1979; Lee and Pimentel, 1981a,b; Long et al., 1982)

In 1955 Pimentel was recognized by promotion to tenure and by award of a Guggenheim Fellowhip, and in 1959 by promotion to full professor and the Precision Scientific Award in Petroleum Chemistry of the American Chemical Society. Pimentel's lab was always exciting; my years as his student, 1960-1963, seemed particularly so. George had just finished the hydrogen bond book (1960,2), and matrix isolation was an established technique but still delivered new and inexplicable phenomena along with great results. Ken Herr was building the rapid scan IR instrument (1965,1). George was working intensely on the CHEM Study text for high schools (1960,3). There were visitors from around the world. George's administrative assistants, Teri Doizaki, who became the department's management services officer, and Suzy Arbuckle, were hard pressed to keep everything on an even keel. I will always remember a group of us sitting at a picnic table by the pool with David Buckingham at George's home in Lafayette talking quantum mechanics. Driving through the night fog to the Western Spectroscopy Association conference at Asilomar listening to famous professors discuss the latest sense and nonsense from various labs was equally memorable. Deference to rank and seniority was not part of a discussion with George. At the weekly group seminar we learned from George that the literature could contain serious mistakes and that Mother Nature was constantly attempting to lead scientists, and especially oneself, to false conclusions and ruined reputations. For nonscientific diversion we watched to see how long it would take the new postdoc from Europe or Asia to address the professor as George. Although George's first wife, Betty, daughter Chris, and twin daughters, Jan and Tess (early teens in 1960) did not often frequent the lab, the daughters were often in the office and frequently twirled Pop-O's old rotating oak bookshelf. George's family was very much a part of the research group family and vice versa. Parties at home around the pool in summer and during the Christmas break were a regular part of all of George's years in Berkeley.

THE CHEM STUDY PROJECT

In 1960 the CHEM Study project (1960,3) was born under the directorship of J. Arthur Campbell of Harvey Mudd College and guided by a steering committee headed by Nobel Laureate Glenn T. Seaborg. Campbell and Seaborg selected Pimentel to serve as editor of the written materials, with the intimidating challenge of producing an entire book in time for use in the fall of the same year with the help of 20 talented teacher coauthors. As written materials began to accumulate Pimentel organized them, revised them, and infused continuity of style and pedagogy. There were three editions: the first, produced during that first frantic summer and fall of 1960, and then two subsequent revisions in 1961 and 1962 based upon trials in high schools throughout the United States. In each one of these editions virtually every word was handwritten at least once by Pimentel. By the time the hardcover edition appeared in January 1963 it was a smooth, intelligible, and useful text that abruptly brought chemistry instruction in high schools up to date.

Accompanying this book was a set of 26 films. With David Ridgway as film director, Pimentel wrote the scripts for five of these films, appeared in two of them as the principal demonstrator, and narrated the other three. In addition, he appeared in two teacher preparation films. “His filmmaking experience in CHEM Study, combined with his demonstrated interest in science and society, led to his involvement in "Wondering About Things," a film about the controversial role of science and technology in modern life, intended for general audiences. He wrote the first script and appeared briefly in the film, which appeared in 1970 and has been viewed by an estimated 2 million people in public theaters and on television."[4]

The success of the CHEM Study project is indicated by the following statistics:

- Over 1 million copies of the textbook *Chemistry, An Experimental Science* were sold.
- Three authorized but independent revisions of the text have been produced.
- Many subsequent texts have used the CHEM Study inquiry model.
- The text has been translated into the following languages: Chinese (Taiwan), French, German, Gujarati, Hebrew, Hindi, Italian, Japanese, Korean, Portuguese (Portugal and Brazil), Russian (unauthorized), Spanish (Spain and Colombia), Thai, and Turkish.
- The films, always including some of the five films written by Pimentel, have been released as video tapes and translated into the following languages: Danish, French, German, Greek, Italian, Spanish (Spain and Latin America), and Swedish.
- All royalties were returned to the U.S. Treasury and the entire cost of the CHEM Study project was repaid one and a half times.

Pimentel understood the need for a high school chemistry course that would draw people into careers in science and engineering. He saw this as a national and global problem, understood that he could do the job on that scale with the help of good teachers and by building a strong national testing network, and accepted the challenge as presented by his colleague Glenn Seaborg, who was chancellor at the time. During the late 1980s he served as principal investigator for Science for Science Teachers (S_4ST), a summer National Science Foundation program for middle school science teachers, which he had encouraged a local high school physics teacher, Penny Moore, to create. They involved leading Berkeley chemistry, physics, geology, and biology faculty members to enhance the science backgrounds of middle school teachers from all parts of the United States.

INFRARED PHOTOCHEMISTRY

Pimentel (Pimentel, 1958a) and Pimentel and Baldeschwieler (1960,4) opened the field of infrared photochemistry by showing that *cis*↔*trans* isomerization could be caused by excitation of specific vibrational transitions of *cis*-HONO (nitrous acid). This was the first chemical transformation ever induced by infrared photolysis (1960,4; Hall and Pimentel, 1963). Later a similar study was conducted on the light-induced matrix isomerization of unstable forms of N_2O_3 (Varetti and Pimentel, 1971).

The much sought mode-selective excitation of bimolecular chemical reactions is elusive under normal reaction conditions. Pimentel recognized the possibility that a cryogenic matrix might provide environmental conditions in which this goal could be achieved. A number of bimolecular reactions have now been studied in solid inert gas matrices with tuned-laser, hence vibrationally selective, excitation of one of the reactants (Frei et al., 1981; Frei and Pimentel, 1981; Frei and Pimentel, 1983a; Knudsen and Pimentel, 1983; Cesaro et al., 1983; Frei and Pimentel, 1983b; 1985,2). Distinct evidence for mode-specific influence on the quantum yield has been found for the F_2+C_2H_4 reaction, (Frei and Pimentel, 1983a) F_2+*trans*-1,2-$C_2H_2D_2$, (Frei and Pimentel, 1983a) and for F_2+allene (Knudsen and Pimentel, 1983). This is the first clear demonstration of mode-selective excitation of bimolecular reactions. Pimentel's mode-selective bimolecular reactions and conformational changes work because the vibrational modes of small polyatomic molecules are relatively pure and weakly coupled at energies up to a few thousand wave numbers. Reactions with activation energies this low are rapid at room temperature, and thus this selectivity is limited to cryogenic systems.

RAPID SCAN INFRARED SPECTROSCOPY

In 1961 Pimentel set out to do rapid scanning infrared spectroscopy to study the spectra and kinetics of free radicals. Together with his student K. C. Herr he adapted the newly developed fast photoconductive Ge infrared detectors for this purpose (1965,1). They built large flash lamps and long cells for flash kinetic spectroscopy in the infrared. Consequently they improved time resolution in infrared spectroscopy by about six orders of magnitude. The first transient free radicals ever detected by IR in the gas-phase were CF_2 (1965,1) and CF_3 (Carlson and Pimentel, 1966). A series of papers traced the elimination of successive obstacles (1965,1; Pimentel and Herr, 1965; Pimentel, 1965; Herr et al., 1967). As sensitivity was improved, resolution became sufficiently good to reveal the rotational fine structure of CF_2 and consequently its molecular structure (Lefohn and Pimentel, 1971). The rate of recombination of CF_3 radicals to form C_2F_6 was carefully measured and found to have an activation energy near 800 cal rather than the presumed value of zero (Ogawa et al., 1970). The gaseous methyl radical was finally detected and its out-of-plane bending force constant measured (Tan et al., 1972).

Pimentel's laboratory maintained a unique position in rapid scan infrared spectroscopy since no other laboratory in the world was able to do more than duplicate some of the transient species spectra recorded earlier at Berkeley. It was not until the early 1980s that laser techniques began to compete in the recording of infrared spectra of short-lived species.

THE CHEMICAL LASER

With this rapid scan spectrometer Kasper and Pimentel discovered IR light pulses from the first chemical lasers, the iodine photodissociation laser (1964,1) and the HCl chemical laser (1965,2). The short, powerful flash of the rapid scan IR system permitted reactants to be prepared fully mixed on a time scale short compared with reaction times and especially compared with vibrational relaxation times; thus, a gain medium was produced with proper selection of the reaction. The long, multipass cells with mirrors provided the needed feedback and thus laser oscillation. Finally, the detectors permitted the observation of the resultant microsecond pulses. Thus, it was the unique capabilities of the Pimentel lab combined with an understanding of the time scales of mixing, reaction, relaxation, and radiation that permitted Pimentel to succeed where many others had failed.

At the time that they reported their discovery of the iodine photodissociation laser at the first Conference on Chemical Lasers (September 1964), there was speculation about more than 100 possible chemical reactions and 60 photodissociation reactions for producing laser radiation. There were even suggestions that reactions might produce distributions of excited states that were always nearly thermal and never inverted. Despite the multitude of suggestions, the only operating laser mentioned at the San Diego symposium was the I* photodissociation laser (1964,1) described by Kasper and Pimentel.

In 1961 Polanyi first pointed out the possibility of chemically pumped lasers based upon vibrational excitation.[5] In this early and prescient note he proposed four potential reactions, one of which was the $H+Cl_2$ reaction. Following that lead, Kasper and Pimentel published the detection of HCl laser emission from the H_2/Cl_2 explosion in 1965 (1965, 2). Polanyi continued his elegant development of the infrared chemiluminescent method for observing energy distributions in exothermic reactions.[6,7] These complemented the rapid expansion of chemical laser discoveries that emerged from Pimentel's laboratory following the pivotal discovery of the $F+H_2$ laser by Kompa and Pimentel (1967). Thus Pimentel pioneered the conversion of chemical energy released as product vibrational excitation into laser light.

Since that time Pimentel led the chemical laser field with the development of new lasers and with their application to research on reaction dynamics. The emphasis was on the discovery of chemical lasers based upon new types of reactions and on the development of methods by which kinetic information could be extracted from the laser performance. He was able to produce lasers operating on vibrational overtone transitions and on pure rotational transitions of hydrogen halides for states as high as $J = 31$ (1984; Suchard and Pimentel, 1971; Cuellar et al., 1974).

The importance of this field lies in its contributions to our understanding of chemical reaction dynamics and in its potential applications. The two most powerful chemical lasers were both discovered in Pimentel's laboratory, the iodine atom $^2P_{1/2} \rightarrow {}^2P_{3/2}$ photodissociation laser and the $F+H_2$ chemical laser. Chemical lasers offer information about the way energy is distributed among the degrees of freedom of the products. Such information reveals intimate details about the dynamics of the reactive collision and the nature of the transition state. It indicates, through microscopic reversibility, the relative importance of particular degrees of freedom in surmounting an activation energy barrier. It suggests the possibility of controlling chemical reactions through selective excitation of reagent energy states.

In 1966, while the chemical laser work was progressing rapidly, Pimentel was elected to the National Academy of Sciences and in 1968 to the American Academy of Arts and Sciences. In 1985, 1987, and 1989 he was elected to the American Philosophical Society, the Royal Society of Chemistry (Great Britain) as an honorary fellow, and the Royal Institution of Great Britain as an honorary member, respectively.

THE ASTRONAUT COMPETITION

In the middle of his term as Chemistry Department chair (1966-1968) Pimentel applied to become a member of the first cohort of scientist astronauts. Another applicant (personal communication, letter, November 1989, from Gerard K. O'Neill) wrote of that experience:

> When I first met him, it was April 1967, and we two were the oldest among seven finalists being given examinations that week at the Air Force School of Aerospace Medicine. . . Two months later we were together again for a day at the Manned Spaceflight Center at Houston. By then we had learned that in the National Academy of Sciences' evaluation of the thousand candidates who had applied, George had been ranked number one. He would in fact have been taken into the program had it not been for an obscure, very minor abnormality of one retina, something that wouldn't have mattered in any real task. . . In the final selection interview, when he was asked how he would react to being offered a two-year trip to Mars, with high risks involved, his instant answer was where do I sign up?
>
> I have never met anyone else who brought to his teaching, his writing, his research and his administrative and governmental tasks the youthful eager-

ness that George possessed always. His great experience, acquired over many decades, never diminished in the slightest his freshness of outlook, his willingness to welcome new ideas, and his delight in them. His youthful spirit must be one of the main reasons why he is, for all of us, a man to admire and love.

Since these first science astronauts saw very little action and since his contributions in Berkeley were so highly valued, George's friends and family were all quite content that he was not chosen.

INFRARED EXPLORATION OF MARS

The infrared spectroscopic technique furnishes the most definitive analytical technique available for remote determination of the composition of the Martian atmosphere. To conduct such measurements within the space, weight, and power constraints presented to spacecraft instrumentation and at the low light intensities available at Mars required, in 1969, an entirely new instrument design. The rapid scan spectroscopic experiment in Pimentel's laboratories and its builder, K. C. Herr, proved to be the key to this formidable challenge. Pimentel and his coworkers innovated a new type of spectrometer, and took full advantage of the latest developments in semiconductor detector and IR filter technology to reach the sensitivity levels needed. The flight instruments were constructed and assembled in the Berkeley laboratories, notwithstanding vigorous objections from the Jet Propulsion Lab, at which nearly all other instrumentation was built.

In retrospect the *Mariner* 6 and 7 infrared spectrometers can be seen to have been one of the most productive of new scientific information of all of the scientific instruments in those two missions. The primary goal was to determine the atmospheric composition. The data gave quantitatively the presence of three constituents: carbon dioxide, carbon monoxide, and water vapor. The absence of some 39 other possible gaseous constituents was ascertained, with laboratory-established sensitivity limits usually in the parts-per-million range. Notably absent were the molecules that might have been indicative of or relevant to the possible existence of life on Mars—oxides of nitrogen, ammonia, and carbon-hydrogen compounds—as well as those suggestive of active volcanism—hydrogen sulfide or oxides of sulfur (Horn et al., 1972).

The secondary missions of the infrared instrument were equally successful. The characteristic spectral signature of solid CO_2 demonstrated the polar cap composition (1969). The presence of hydrates in the Martian surface minerals was evident and distinguishable from ice near the edge of the receding polar cap (the polar collar) (1974). Upper atmosphere solid CO_2 clouds, analogous to terrestrial cirrus, ice clouds, were detected even near the Martian equator (1970,1). Perhaps most remarkable was the topographical information derived from the spectral data. With the best geographical resolution yet available, the spectrometer displayed surface altitudes varying by 8 kilometers and carbon dioxide surface pressures varying from 3.7 mbars to 8.1 mbars. The most spectacular terrain feature discovered was undoubtedly the region called Hellas, which was found to be a deep depression 1700 kilometers wide and dropping 5.5 kilometers from its rims (1970,2). These results were a truly remarkable achievement. Many doubted that such a spectrometer would be feasible at all, much less that it could be built away from the spacecraft facilities at the Jet Propulsion Laboratories. Most doubted that conclusions could be drawn even if spectra were recorded. Pimentel's truly exceptional creative genius, raw courage, and experimental finesse are clearly displayed in this work.

PUBLIC SERVICE

Pimentel served as deputy director of the National Science Foundation under Richard Atkinson from 1977 to 1980. Upon his return to Berkeley in 1980 Pimentel remarked[8] about his involvement in public service:

> It all began right here in Berkeley, when I got involved in an informal evening discussion group organized by some friends in the Poli. Sci. department. Once a month, a handful of us—about half from departments like political science, history, and economics, and the other half from the sciences—would get together, have dinner, and talk about issues in science policy.
>
> The experience of discussing and thinking about science policy led to my accepting a term of service on the National Academy of Sciences' committee on science and public policy. There, I acquired a reputation for talking loud and long about how scientists should get involved in government policy making. So when I was offered the job at NSF, it was really a case of put up or shut up. I accepted the job for an initial two-year term, and then it was extended to a third year because there was still a lot I wanted to accomplish.
>
> Sure I'm glad to be back in academia—back to my research and my students—but I'm glad I did it. It was a valuable experience, and, if anything, I'm talking even more than I was before about the need for scientists to undertake this kind of duty. It has its frustrations; it's hard to move the system sometimes. But if working scientists don't pick up this burden . . .

Pimentel served on National Academy of Sciences' committees including the Panel on Atmospheric Chemistry (1975-1977), Committee on Science and Public Policy (1975-1977), Nominating Committee (chair, 1983), Board on Chemical Sciences and Technology (1982-1988), and the Committee to Survey Opportunities in the Chemical Sciences (chair, 1982-1986). He served NASA on the Lunar and Planetary Missions Board (1967-1970). He served the American Chemical Society on the Editorial Board of *Chemical and Engineering News* (1982-1984), the Committee on Chemistry and Public

Affairs (1982-1984), and as president-elect (1985), president (1986) and immediate past president (1987).

In 1985 the National Academy of Sciences and the National Research Council published the report *Opportunities in Chemistry*, better known as the Pimentel Report for its committee chair (1985,1). Committee member Alan Schriesheim, formerly vice president for research at Exxon and at the time director of Argonne National Laboratory, commented[9] that

> there was a real effort to involve the various segments of the chemistry community—the academic, industry, and government sectors—and then, within these sectors, the various disciplines of chemistry—physical chemistry, organic chemistry, biochemistry, and the rest. Early on the decision was made that the effort would be to identify areas that the community in a sense could coalesce around and say that these were deserving of additional funding. These were to be areas that were particularly exciting whether because of intellectual ferment or because they had high societal impact. The report itself was geared to have impact on policy makers who would be involved in funding decisions.

Pimentel was inspired to take on this enormous task by Presidential Science Adviser George Keyworth's 1982 advice to the President on areas of science that merited more funding. Chemistry was not one of the areas. The report is organized into three areas of service to societal need: (1) new processes, new products, and new materials; (2) food, health, and biotechnologies in relation to the understanding of complex molecular systems; and (3) national well-being through an understanding of the chemistry of the environment, continued economic competitiveness, and increased national security. Although the report did not coincide with federal budget surpluses, it did have an impact on funding decisions in chemistry. In succeeding years I often heard program officers in research agencies argue for support of programs and new initiatives by quoting recommendations from the Pimentel Report. Pimentel stated, “Most of the book is about what chemistry does for society.”

In 1987 *Opportunities in Chemistry* appeared under the title *Opportunities in Chemistry: Today and Tomorrow*[10] rewritten to be suitable for advanced high school students and college nonscience majors. His daughter and coauthor, Janice Coonrod, dedicated some of the seven translations of the volume to her father; it reads in part:

> It comes as no surprise that the work to which he devoted his life continues to enlighten and enrich others even after his death. Although this publication is just one achievement in a career studded with outstanding accomplishments, it does in many ways uniquely symbolize the efforts of his lifetime. My father was a tireless advocate of the science of chemistry. It was his strong desire that chemistry might become accessible to all young people from all walks of life so that they might build a citizenry capable of making informed and responsible decisions about the use of chemistry on this planet. It was his wish that the general population might come to appreciate the integral part chemistry plays in solving human problems and responding to society’s needs. And foremost, it was his desire to share his unbridled enthusiasm for the science of chemistry and to stimulate, excite, and encourage individuals who might be interested in the study of this amazing discipline.

Notwithstanding his extensive public service, Pimentel vigorously continued his exploration of chemical reactivity through matrix experiments, chemical laser studies, and with new ventures into organometallic chemistry (Weiller et al., 1989), and photochemistry on metal surfaces (1988).

Pimentel was selected for more than a dozen prestigious lectureships at universities throughout the world. He received an extraordinary number of awards and medals, including the Wolf Prize in Chemistry (1982), the U.S. National Medal of Science (1985), the Benjamin Franklin Medal of the Franklin Institute (1985), the Robert A. Welch Award in Chemistry (1986), and the Joseph Priestley Medal of the American Chemical Society (1989), its highest honor. He received honorary degrees from the University of Arizona, Rochester University, and the Colorado School of Mines.

He was a devoted father to Chris, Jan, and Tess, his daughters with his first wife, Betty; loving stepfather of Vincent and Tansy, children of his second wife, Jeanne; and proud grandfather of five grandchildren.

Pimentel prided himself on always keeping in good physical condition. His favorite participation sports were squash (for many years with Berkeley professor Robert E. Connick as a regular and very much taller opponent) and softball (with members of his research group and other chemistry colleagues as participants). He also played many younger colleagues. To judge by conversation at lunch or at Café Strada, to be able to match or better George on the squash court seemed as difficult as achieving promotion to tenure and often the source of comparable satisfaction. Many of us have fond memories of George dressed in sweats heading off to compete wearing glasses with frames that had been epoxy repaired more than once. He was active to the very end, and his energy and enthusiasm and enjoyment of sports characterized his approach to life. He chose his own epitaph: "He went to the ball park every day and he let them know he came to play."

I AM MOST GRATEFUL to George's daughters, Chris, Jan, and Tess; to his wife, Jeanne; to his research students, Lester Andrews, John Baldeschweiler, Ted Becker, Bill Klemperer, and Geri Richmond; and to Jane Scheiber in the University of California chemistry dean's office for valuable additions and corrections to this memoir.

NOTES

1. A complete bibliography of Pimentel's work and a list of his students have been published in *J. Phys. Chem.* 95(1991):2610-2615. His papers are archived at the University of California's Bancroft Library.

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