NATIONAL ACADEMY OF SCIENCES

EDWARD PURDY NEY

1920—1996

A Biographical Memoir by

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UNIVERSITY OF MINNESOTA regents professor emeritus Edward Purdy Ney was a gifted, dedicated scientist and teacher whose research career spanned the period from the onset of World War II through the early 1990s. He made important contributions to nuclear physics, cosmic-rays astrophysics, heliospheric studies, atmospheric sciences, and infrared astronomy. Throughout his career, he chose to be at the frontier and to work in emerging fields of science, accompanied by a small, devoted group that included colleagues, technicians, engineers, and graduate students. As a field developed and became more crowded, he sought a new and often very different research frontier, while remaining securely anchored to the University of Minnesota from 1947 onward. Ney pioneered the development of sophisticated particle detector systems, including cloud chambers and scintillation counters, for studies at the top of the atmosphere. He flew the first space science experiment on NASA manned flight, *Gemini 5*, and founded the O'Brien Observatory in Minnesota, where he developed new Dewar and bolometer technology to make some of the early observations in infrared astronomy. He participated in the seminal discovery of heavy nuclei in the galactic cosmic radiation.

Together with Nick Woolf, he showed that silicate and carbon grains, the building blocks of the planets, form in circumstellar shells around aging stars. He was an excellent teacher, particularly at the undergraduate level. Ney lived his life and conducted his research with an unconventional flair and frankness. Ney relentlessly sought truth and took delight in challenging authority and the conventional wisdom when he believed they were wrong. He spoke out forcefully, not only on scientific issues but also on his fellow scientists, the space program, his university, the nation's nuclear policy, and governance of the National Academy of Sciences.

THE EARLY YEARS

Ney was born on October 28, 1920, in Minneapolis, Minnesota, the son of Otto Fred and Jessamine Purdy Ney and was raised in Waukon, Iowa, a small farm town in the northeast corner of Iowa, 18 miles west of the Mississippi River. Ed's father was a stern disciplinarian who traveled frequently selling farm supplies. His mother was partially disabled by an attack of polio in her youth. She finished two years of junior college and taught kindergarten in Waukon. Their mother read to Ed and his younger sister Nancy, nurturing their curiosity and love of learning. In the eighth grade, Ed and a friend started and produced a school newspaper. By the time he reached high school, according to his sister Nancy, Ed had developed a strong interest in science, math, and girls. The local high school had a well-rounded science curriculum, which provided Ed with courses in general science, zoology, chemistry, and physics. He was especially influenced by Howard Moffitt, who taught several of his courses and later became an administrator at the University of Iowa.

Ed was disdainful of other courses and confined his reading mainly to science and to his special hobby, photography. Nevertheless, he developed a mastery of the English language that was reflected in his writing, in his ability to spot grammatical and spelling errors in his students' theses, and especially, in the edicts and pronouncements that came down from Minnesota's deans and higher authorities.

One of Ney's early clashes with authority and conventional wisdom occurred in high school. His focus on physics, math, and chemistry to the apparent detriment of his other more routine studies did not endear him to the principal, who informed Ney that "nobody who ever graduated from Waukon High School has ever done anything in science and neither will you." Ney vowed to prove him wrong.

In 1938, at the age of eighteen, Ney entered the University of Minnesota. In 1940 he took a class from Alfred O. C. Nier. During the course, he asked if he could play around with one of Nier's oscilloscopes. Ney's ability and enthusiasm so impressed Nier that he hired the twenty-year-old Ney to make mass spectrometer measurements of carbon dioxide samples, in which the ratio of ^{13}C / ^{12}C had been increased by passage of the CO_2 through a thermal diffusion column set up in an abandoned elevator shaft. Nier, ever careful of the use of his research funds, paid Ney thirty-five cents per hour. At a time when the use of radioactive tracers was just beginning, chemists and biologists used the ^{13}C-rich CO_2 for metabolism studies and as a tracer for photosynthesis.

John Bardeen, then a young assistant professor at Minnesota, theoretically calculated the expected enrichment from the thermal diffusion column. As Ed described it in his notes:

> Bardeen's calculation and my measurement disagreed by a factor of two. We were getting too much ^{13}C . Bardeen shook his head and went back to

the office for a week to try again. This calculation was not elegant physics like the BCS theory of superconductivity. It involved convection and messy assumptions. However, John was convinced there was a problem and finally Al Nier asked me to describe the power measurement. The columns were fed by an autotransformer and, when I measured the power to one, I had disconnected the other. Bardeen was right, and I took an electrical engineering course. The primary lesson was that John Bardeen was one smart guy. After World War II he went to Bell Labs and won his first Nobel Prize.

At the very beginning of the U.S. program to develop the atomic bomb, Al Nier had produced a 0.1-microgram separated sample of ^{235}U and ^{238}U, which had been used to show that ^{235}U was the isotope that underwent slow neutron fission as predicted by Bohr and Wheeler. In mid-1940, Nier was asked by the Uranium Committee to separate a 5-microgram sample of ^{235}U for the determination of nuclear cross-sections and neutron production rates. Nier designed a new mass spectrometer, which Ney and another undergraduate, Robert Thompson, kept going twenty-four hours a day for three months to produce the required sample. Nier then undertook the design and development of a special mass spectrometer for the analysis of processed UF_6. With the assistance of Ney, Mark Inghram, and the department's machine shop they produced three instruments in six months. These were to become the key assay instruments used by the Manhattan Project to measure the enrichment of uranium produced by the different separation methods then under development at Oak Ridge, Columbia, the Naval Research Laboratory, and the University of Virginia. Out of this collaboration, Alfred O. C. Nier and Edward P. Ney formed a very close personal and professional friendship that lasted until Nier's death in 1995.

On June 20, 1942, just after graduating from the University of Minnesota with a bachelor of science degree in physics, Ney married June Felsing. June had caught Ed's attention at a dance during their undergraduate years at the university. When she mentioned that she was taking a physics course taught by the department chairman, Ed asked her what her grade was. Hearing "A," Ed was impressed, but skeptical. Ever the careful scientist, he checked her record, found she had indeed gotten an "A," and promptly began courting. Their union lasted until his death and produced daughter Judy and sons John, Arthur, and William.

Shortly after their marriage, the Neys moved from Minneapolis to Charlottesville, Virginia. Ney took along one of Nier's new mass spectrometers and became the mass spectrometer specialist assigned by the Manhattan Project to work with Jesse Beams at the University of Virginia. He also enrolled as a graduate student in the Physics Department. Beam's group, a part of the Manhattan Project, was investigating the feasibility of using centrifuges to enrich uranium. Ney used the assay instrument developed at Minnesota to analyze the uranium samples produced by centrifuging at Virginia and also those produced by thermal diffusion at the Naval Research Laboratory. The Virginia centrifuges were very promising as pilot models, and Standard Oil of New Jersey began developing a production facility. Because this effort did not go well, General Groves came to Charlottesville in 1944 and closed down the Virginia program. (Many years later centrifuging became the most energy-efficient way to produce moderate amounts of enriched uranium). Ed then worked with his Virginia colleagues developing circuits and systems for gun control on naval ships and the guidance of small missiles. He maintained a lifelong interest in and concern about nuclear weapons.

For his Ph.D. thesis, which was classified, Ney measured the self-diffusion coefficient of UF_6. This constant was an important number, because knowledge of it, as well as the self-diffusion coefficient and the viscosity, determines the molecular force law and predicts the thermal diffusion coefficient. It turned out that UF_6 molecules have an inverse fifth power law of force for which the thermal diffusion coefficient is zero.

In 1944 their daughter Judy was born and two years later their son John. In 1946 the University of Virginia awarded Ney a Ph.D. Four years earlier, Ney had arrived in Virginia, a self-assured new college graduate who appeared much younger than his twenty-one years but whose research experience already extended beyond that of many fresh Ph.D.s. In only four years, he had worked more than full-time on the Manhattan Project and other defense-related efforts, juggled graduate courses, written a Ph.D. thesis, and won the admiration and respect of his colleagues at Virginia and the Naval Research Laboratory. The University of Virginia asked him to join their faculty as an assistant professor.

THE COSMIC RAY AND SKYHOOK BALLOON ERA

In 1946, with the end of the war, it was time to seek new research frontiers. Ney taught a course based on Heisenberg's book *Cosmic Radiation* and decided to shift his field of research from mass spectroscopy to cosmic-ray studies. Ney, Jesse Beams, and Leland Swoddy began an underground experiment in the Endless Caverns near New Market, Virginia. While waiting to get substantial results, Ney wrote a theoretical paper on the cascade component of cosmic radiation. According to Ney, the paper, while not very profound, caught the eye of John T. Tate, editor of *Physical Review* and professor of physics at the University of Minnesota. Tate was looking for bright young physicists to start a project to study cosmic rays with the aid of large plastic balloons invented by Jean Piccard and manufactured by the General Mills Research Laboratories in Minneapolis. Tate offered Ney an assistant professorship at the University of

Minnesota, which Ney promptly accepted. Although there is no documentary evidence, Ed's mentor Alfred O. C. Nier probably played a role in the return of his young prodigy. In 1947 the Neys and their two children returned to Minneapolis. Except for a sabbatical in Australia and two one-quarter leaves of absence, Ney spent the rest of his life at the University of Minnesota.

In 1947 Ney, together with Ed Lofgren and Frank Oppenheimer, formed the Minnesota cosmic-ray group and began to use nuclear emulsions and cloud chambers for studies of cosmic rays. Soon, Phyllis Freier joined the team as a graduate student. Together they pioneered the use of balloon-borne cloud chambers and nuclear emulsions. For the first time it became possible to study the nature of the primary cosmic rays at the top of the atmosphere. This effort paid off in 1948, when, in a joint balloon flight with Bernard Peters and Helmut L. Bradt of the University of Rochester, they discovered "heavy" particles in the cosmic radiation. Their data showed that cosmic rays are not electromagnetic radiation at all. Instead, they are high-energy nuclei of the elements stripped of their electrons. When astrophysicists found that the primary cosmic radiation consisted of elements from hydrogen through iron and that their relative abundances were similar to those deduced from astrophysical studies, they realized the studies of cosmic radiation could play a major role in astrophysics, as well as in understanding the origin and transport of energetic particles in the galaxy. Fifty years later it remains a very active research field.

Shortly after this major discovery, there were significant changes of personnel in the original cosmic-ray group. First, Lofgren left to supervise the construction of the Berkeley bevatron. Next, the university forced Oppenheimer to resign, because he had concealed his pre-war membership in the Communist Party. From 1949 through 1962, Ney led the cosmic-ray group. In 1949 John R. Winckler joined the Physics Department. Previously he had been at Princeton, where he had been carrying out cosmic-ray studies at balloon altitudes. The university appointed Ney associate professor in 1950. A second son, Arthur, was born on September 10, 1951, and a third, William, on August 9, 1952. In 1955 Ney became a full professor.

Meanwhile, Charles Critchfield, a theoretical physicist at Minnesota, became concerned about the lack of electrons in the cosmic radiation. He noted that if all the particles were positively charged then the Sun itself should charge up in about a year and repel the positive cosmic rays. As we know today, this idea is incorrect, but it stimulated Ney and Sophia Oleksa, a graduate student, to conduct a series of cloud chamber flights using both horizontal and vertical lead plates to try to measure the flux of electrons. Although they did observe electron showers, the number of events they observed could be explained as the result of the decay of pi mesons produced in the material above the chamber and their subsequent decay into gamma rays. Although Ney and Oleksa did not detect electrons in the primary radiation, they did set an upper limit on the electron flux of about 1% of the primary particles with energies above 1 GeV. Ten years later, when James Earl and Peter Meyer independently measured the flux of primary electrons they found the flux to be only slightly below the limit set by Critchfield, Ney, and Oleksa.

In 1950 Ney shifted from cloud chambers to scintillation counters and made one of the first measurements of the abundance of the elements using a scintillation counter. Shortly thereafter Ney and other cosmic-ray physicists became frustrated with a number of unexplained failures of large plastic balloons. In one celebrated case, a graduate student's payload separated from its parachute, free fell from high altitude, and crashed through the roof of an Iowa farmhouse. As a result, Ney, Winckler, and Critchfield undertook a high-priority, classified military project, supported jointly by the Army, Navy, and Air Force, to improve performance of high-altitude balloons and to develop a system that could photograph military installations in the Soviet Union. Ultimately, this became a multimillion-dollar project involving some thirty-five people. In late 1955, after the development of the U2 aircraft, the Air Force and subsequently the Army abruptly withdrew their support, since they no longer needed balloon-borne surveillance. In August 1956 the project closed down. A number of techniques developed in this research program, such as the duct appendix, super-pressure tetroon, and the natural shape balloon, continue to be used for cosmic-ray and atmospheric research, both here and abroad. Funding from the Office of Naval Research continued, making it possible for Ney and his graduate students to conduct an extensive atmospheric research program that resulted in eight Ph.D. theses. As Ney observed in his research notes, this return to science was a blessing that led to many significant developments:

> John Kroening studied atmospheric small ions, invented a chemiluminescent ozone detector, and did a seminal study of atmospheric ozone. John Gergen designed the "black ball" and studied atmospheric radiation balance, culminating in a national series of radiation soundings in which a majority of the weather bureau stations took part. Jim Rosen studied aerosols with an optical coincidence counter, which was so good it still has not been improved; he was the first to discover thin laminar layers of dust in the stratosphere and to identify the source as volcanic eruptions. Ted Pepin participated in photographic observations from balloon platforms, and has subsequently carried this interest further with optical observations of the Earth's limb from satellites.

As the balloon project wound down, Ney also began to work more closely with the emulsion group, which at the time consisted of Phyllis Freier and several graduate students. Under Ney's leadership, Peter Fowler of the Bristol emulsion group spent the 1956-57 academic year at Minnesota. In a joint effort, the two groups systematically measured the flux of alpha particles as a function of energy and found that it reached a maximum at about 300 MeV/nucleon. Later, during the International Geophysical Year, Ney, Winckler, and Freier applied techniques developed in the balloon program to keep a balloon in the air continuously during a period of intense solar activity. They observed protons from the Sun during several solar flares. In November 1960, during a giant solar flare, the Minnesota group measured a flux of solar protons that exceeded the normal cosmic flux by a factor of 10,000. An astronaut in space beyond the magnetosphere would have received an exposure of about 60 roentgens, or about a tenth of the lethal dose. Observing that the flux of galactic cosmic rays increased by a factor of three during the period of minimum solar activity, Ney proposed that this variation would lead to a variation in the ion density in the atmosphere and that this might prove to be a connection between solar activity and the weather.

Still in search of the elusive electrons in cosmic radiation, Ney and Paul Kellogg, a theoretical physicist at Minnesota, proposed that an appreciable fraction of the visible light in the solar corona came from synchrotron radiation of high-energy electrons spiraling about solar magnetic lines of force. Their theory predicted a non-radial component of polarization in the light of the corona. They set out to check their theory during the 1959 eclipse of the Sun. First there were formidable logistics problems to solve. In a little over two years, they prepared a proposal, obtained funding of $60,000, built three instruments, and flew from Minneapolis to French West Africa in an ancient DC4. There they set up instruments at three sites along the path of the eclipse. During the eclipse, good data were obtained at two sites, but the third was clouded over. The measurements disproved Ney and Kellogg's theory, for they showed that the light of the corona came from Thomson scattering as postulated by solar physicists, not from synchrotron radiation. Although this result was a disappointment, the work led to the development of cameras and polarimeters that Ney and his students later used to study dim, diffuse sources of light. Two decades later, Ney participated in another eclipse expedition to observe the solar corona in the infrared. Later he commented on the differences between the two expeditions:

> Although the overall support for science was less, then it was possible for a university group to conceive and carry out an expedition. In 1980 we participated in the National Science Foundation's expedition to observe the eclipse in India. It was like a Boy Scout outing with administrators and managers, and even a doctor. But it wasn't much fun, and it cost a lot more.

The coronal experiment stimulated Ney's interest in dim, diffuse sources of light in astrophysics. He undertook to understand the origin and nature of the zodiacal light. He and his students flew cameras and polarimeters, developed for the coronal experiment, on balloons, *Mercury* and *Gemini* flights, and two orbiting solar observatories. These flights showed that the zodiacal light was highly polarized, of constant or slowly varying intensity, and that it was produced by the scattering of sunlight from dust grains. As the first scientist to fly an experiment on a NASA manned space flight program, Ney spent a good deal of time briefing the astronauts in the Moorhead Planetarium in Chapel Hill. Ney found it fun to get to know the astronauts, but he thought conducting research on a manned spacecraft a hard way to do science.

Although Ney designed instruments for an Orbiting Solar Observatory to study the zodiacal light during the portion of the orbit when the satellite was in the dark, the instruments could also be used to study light sources on Earth. Ney obtained a completely unexpected result when he observed thousands of terrestrial lightning flashes and found that there were ten times as many flashes over the land as over the ocean. As yet, no satisfactory explanation of this observation exists.

In 1963 Ney decided to change from physics to astronomy. He presented his final paper on cosmic rays at the Pontifical Academy in Rome while on his way to Australia to study astronomy with Hanbury Brown and Richard Twiss. Upon his return to Minnesota, in collaboration with two graduate students, Fred Gillette and Wayne Stein, Ney entered the emerging field of infrared astronomy, a field suitable to his pioneering instinct. At that time, there were only two infrared astronomers, Frank Low, then at Rice University, and Gerry Neugebauer at Caltech. With good students, a highly qualified support group, and his own exceptional physical insight and great experimental skills, Ney soon had Minnesota at the frontier of this new research field. To make infrared observations, he founded the O'Brien Observatory and equipped it with a 30-inch infrared telescope. Later, he helped to design the 60-inch infrared telescope for the Mount Lemmon Observing Facility in Arizona. As a result of their infrared observations, Ney and Nick Woolf showed that silicate and carbon grains form circumstellar shells around aging stars. As Ney noted at the time, in a cosmology dominated by hydrogen and helium, it was a relief to find the source of the material that forms the terrestrial planets.

After his retirement, Ney took up yet another field of research: the effect of radioactivity from radon gas on the atmosphere. He thought that the ionization from radon would produce a higher level of ionization in the atmosphere over land that could account for the higher levels of lightning over land, compared to those over the ocean. Unfortunately, Ney's death prevented the completion of this work.

Ney loved to teach. He had a special gift for using novel demonstration equipment to illustrate physics. His award-winning, animated lectures, liberally laced with hilarious wisecracks and anecdotes, gave thousands of students in his introductory courses the opportunity to experience the excitement of working at the cutting edge of science. Beneath the wisecracks and the jokes, students found a man with an absolute, steely insistence on honesty in academic and research work.

In 1961 he lectured in the department's first honors course in modern physics. These lectures were turned into "Ney's Notes on Relativity." The next year he contracted hepatitis on a trip abroad. Instead of quietly recuperating, he used the time at home to turn these notes into a book, *Electromagnetism and Relativity* (New York: Harper and Rowe, 1962). He received the University of Minnesota's outstanding teaching award in 1964.

Ney's enthusiasm and charisma attracted good graduate students to his program. He encouraged them to select their own thesis topic and to conduct their research with a minimum of direction from him. He believed this produced a better and more mature Ph.D. Sixteen students received their Ph.D. under Ney. His methods produced high-quality students. Twice, the position of NASA chief scientist was filled by former students of Ney. Another student helped establish the Stratoscope Program at Princeton, and two students constructed one of the world's largest infrared telescopes at Jelm Mountain, Wyoming. One former student is a member of the National Academy of Sciences. Ney's career demonstrates that great research scientists can, and do, like to teach.

A major reason for Ney's success lay in his ability to attract, stimulate, and direct superb engineers and technicians. He made them full partners in his research and when they contributed in a substantial way to a project, he included them as co-authors of the resulting papers.

Ney's interest and concern extended beyond research. He took an activist role in campus politics. He believed that the students, staff, and faculty were the heart of a strong university and that the administration should serve their interests. He also believed in rigorous academic standards. Once, when invited to serve as the "outside professor" on a Ph.D. final exam, Ney considered the thesis topic to be trivial, not worthy of a Ph.D., and he refused to approve the thesis. Ney then severely criticized the professor who had approved the topic and supervised the work.

Ney did not limit his contributions to the academic arena. As a citizen he maintained a lifelong concern about the impact of science on public policy. He frequently contributed letters and articles to local editorial pages on atomic energy, nuclear weapons, the space program, and the environment. In later years he became deeply concerned about the proliferation of nuclear weapons and the possibility of their use by terrorists.

Edward P. Ney was elected to the National Academy of Sciences in 1971 and the American Academy of Arts and Sciences in 1979. In 1975 NASA awarded him its Exceptional Scientific Achievement Medal. In 1964 the University of Minnesota awarded him the university's Outstanding Teaching Award. Subsequently, in 1974 the university bestowed on him its highest honor, a Regent's Professorship.

As unconventional in his dress as in his work, Ney's red, high-top tennis shoes graced many a formal function, including a National Academy of Sciences garden party and black-tie dinner. Ney liked good cars and he liked to drive them fast. In the late 1940s he chased balloons in a low, black, streamlined Hudson that cruised at 90 miles per hour. He next bought a convertible that traveled even faster. Later, with proceeds from the sale of his book *Relativity and Electromagnetism*, Ney bought his ultimate automobile, a powder-blue Jaguar XKE. Returning from a night's observing at the O'Brien Observatory, Ney conducted an experiment to see how large a fine he would get if he exceeded the 65-miles-per-hour speed limit by a factor of two. Unfortunately, the experiment provided a null result; the Minnesota State Highway Patrol failed to appear.

In his later years, Ney suffered from ventricular tachycardia, a condition in which the ventricles of the heart contract at a high frequency and which can cause death in a short time. Frustrated with his doctor's inability to control the arrhythmia, Ney began to study cardiology. He turned the full force of his research talent on himself and his disease. He searched the literature, and became convinced that the best way to control the disease required a pacemaker that could be commanded to send pulses to the heart at a higher rate than the tachycardia. This action enabled the pacemaker to capture the rhythm of the heart so that, when the doctor slowed the frequency of the pacemaker's pulses, it brought the heart back to its normal rhythm. Ney's last (unpublished) paper, "A Physicist's History of Pacing and Shocking in the Treatment of Recurrent Sustained Monomorphic Ventricular Tachycardia, 1975-1995," gave the history of his illness and documented the results of his research. Ney's last battle with authority was with his cardiologist. Ney wanted to carry the "black box" that controlled the defibrillator with him so that if he had an attack of ventricular tachycardia, he could send the defibrillation command. Conventional wisdom held that the patient must be brought to a hospital for treatment by a registered cardiologist. Unfortunately, authority and conventional wisdom finally won a battle with Edward P. Ney. He died at his home in Minneapolis on July 9, 1996.

He is survived by June, his wife of fifty-four years, and their four children Judy, John, Arthur, and William, a sister Nancy Braun of Atlanta, and nine grandchildren. On July 16, 1996, several hundred people, including friends, family, his cardiologist, colleagues, and former students attended a joyful memorial celebration in his honor at the University of Minnesota.

SELECTED BIBLIOGRAPHY

1945

The power spectrum of the cosmic-ray cascade component. *Phys. Rev.* 70:221-21.

1947

With P. C. Armistead. A self-diffusion coefficient of uranium hexaflouride. *Phys. Rev.* 71:14-19.

1948

With others. Evidence for heavy nuclei in the primary cosmic radiation. *Phys. Rev.* 74:213-17.

1949

With E. J. Lofgren and F. Oppenheimer. Apparatus for cloud-chamber investigations with free balloons. *Rev. Sci. Instrum.* 20:48-51.

With F. Oppenheimer. Wide angle sprays of minimum ionization particles. *Phys. Rev.* 76:1418-19.

1950

With P. Freier. Multiple production of mesons. *Phys. Rev.* 70:337-41.

With C. L. Critchfield and S. Oleksa. The electrons in cosmic rays. *Phys. Rev.* 79:402-403.

1951

With D. M. Thon. A scintillation counter measurement of heavy nuclei. *Phys. Rev.* 81:1069-70.

1956

With W. Elsasser and J. R. Winckler. Cosmic-ray intensity and geomagnetism. *Nature* 178:1226-27.

1957

With others. The low energy end of the cosmic-ray spectrum of alpha-particles. *Philos. Mag.* 2:157-75.

1958

With P. Freier and P. H. Fowler. Cosmic rays and the sun-spot cycle: The primary alpha-particle intensity at sunspot maximum. *Nature* 181:1317-21.

1959

Cosmic radiation and the weather. *Nature* 183: 451-52.

With P. J. Kellogg and J. R. Winckler. Geophysical effects associated with high-altitude explosions. *Nature* 183: 358-61.

With P. S. Freier and J. R. Winckler. Balloon Observations of solar cosmic rays on March 26, 1958. *J. Geophys. Res.* 64:685-88.

1962

With W. A. Stein. Solar protons, alpha particles and heavy nuclei in November 1960. *J. Geophys. Res.* 67:2087-2105.

1964

With F. C. Gillett and W. A. Stein. Observations of the solar corona from the limb of the Sun to the zodiacal light, July 20, 1963. *Ap. J.* 140:292-305.

1969

With N. J. Woolf. Circumstellar infrared emission from cool stars. *Ap. J. Lett.* 155:L181-84.

With D. A. Allen. The infrared sources in the trapezium region of M42. *Ap. J. Lett.* 155:L193-95.

1970

With R. W. Maas and N. J. Woolf. The 10-micron peak of comet Bennett 1969i. *Ap. J. Lett.* 160:L101-104.

With J. A. Vorpahl and J. G. Sparrow. Satellite observations of lightning. *Science* 169:860-62.

1972

With J. G. Sparrow. Zodiacal light observations from the ecliptic to the poles. *Ap. J.* 174:705-16.

1974

Infrared observations of comet Kohoutek near perihelion. *Ap. J. Lett.* 189:L141-43.

1975

With others. Studies of the infrared source CRL 2688. *Ap. J. Lett.* 198:L129-34.

1978

With B. F. Hatfield. The isothermal dust condensation of Nova Vulpeculae 1976. *Ap. J. Lett.* 219:L111-15.

1982

Optical and infrared observations of bright comets. In *Comets*, ed. L. L. Wilkening, pp. 323-39. Tucson: University of Arizona Press.

1987

With R. S. Lively. Surface radioactivity resulting from the deposition of Rn daughter products. *Health Phys.* 52(4):411-15.

1990

With R. D. Gehrz. Confirmation of dust condensation in the ejecta of supernova 1987a. *Proc. Natl. Acad. Sci. U. S. A.* 87:4354-57.

1992

With R. D. Gehrz. 0.7 to 2.3 micron photometric measurements of P/Halley 1986 III and six recent bright comets. *Icarus* 100:162-86.

1995

With R. D. Gehrz, C. H. Johnson, and S. D. Magnuson. Infrared observations of an outburst of small dust grains from the nucleus of comet P/Halley 1986 III at perihelion. *Icarus* 113:129-33.