NATIONAL ACADEMY OF SCIENCES

ALFRED OTTO CARL NIER

1911—1994

A Biographical Memoir by

JOHN H. REYNOLDS

Biographical Memoir

National Academies Press
washington d.c.

Alfred O C Nier

ALFRED OTTO CARL NIER

May 28, 1911—May 16, 1994

BY JOHN H. REYNOLDS

IN MAY 1994 the international scientific community lost one of its most distinguished experimentalists. Alfred Nier, regents professor emeritus at the University of Minnesota, used mass spectrometers of his own design and construction in a manner that can only be likened in breadth and importance to Albert Michelson's use of interferometers to answer scientific questions in numerous and widely diverse fields of inquiry. These questions included how old is the earth; which isotope of uranium is responsible for slow neutron fission; how is the atmosphere of Mars composed; what are the details of nuclide stability in the table of isotopes; what nuclides of great rarity remained to be discovered in nature; how effective are various schemes of isotope separation; and how can mass spectrometry be applied in practical ways to chemical analysis and to leak detection in vacuum systems.

EARLY YEARS (1911-36)

Alfred Nier ("Al" to all who knew him) was born in St. Paul, Minnesota, on May 28, 1911. His parents were German immigrants who came to the United States as youngsters. His father eventually owned and operated a small dry cleaning business. Al had one sister, eleven years his senior, and no brothers. His parents had limited education but did have a deep respect for learning; with him they decided early that he would pursue education beyond high school level. The nearness of St. Paul to the University of Minnesota at Minneapolis enabled him to attend despite limited financial resources. There ensued a remarkable relationship between him and that institution; except for two years (1936-38) as a National Research Council fellow at Harvard and two years on the Manhattan Project (1943-45) in New York City, his entire scientific career was spent there. The university in 1966 recognized his great contributions by naming him regents professor of physics, one of the first five faculty members to receive that honor. They further awarded him an honorary doctorate of science in 1980. At a memorial convocation to honor his life, President Nils Hasselmo quoted another regents professor, who said, “Al Nier was the best thing that ever happened to this place.”

Al showed an early aptitude for mathematics and science. Courses in shop work and mechanical drawing also attracted him and left him with an aptitude for constructing apparatus with his own hands, which served him well in later years. He and boyhood friends with interests in radio, an emerging technology at the time, followed the latest developments in receiver construction, experimenting with new circuits as they were published. Enrollment in electrical engineering at the university followed naturally from these interests and would have fixed his career in that field had it not been for the lack of engineering jobs upon graduation in 1931. He was encouraged to enter physics by physics professor Henry A. Erikson, who recognized Al’s talent early on, as did another mentor, Professor Henry Hartig of electrical engineering.

Professor John T. Tate became Al’s advisor when Al switched to graduate study in physics. Tate, well known among physicists partly because of his editorship for many years of the *Physical Review*, had worked with James Franck in Berlin when energy levels for electrons in atoms was an emerging subject, leading Tate at Minnesota into the field of electron impact phenomena. Many of Tate's students studied ionization potentials of atoms and molecules and cross sections for ionization of molecules subjected to electron impact. The required analysis of the resulting fragment ions led naturally to the development of mass spectrometers in Tate's laboratory. Around 1930 three of Tate's students, Walker Bleakney, Philip T. Smith, and Wallace W. Lozier, made notable contributions to this type of research. The focus on nuclear physics in those times motivated Al to select as a thesis topic the use of mass spectrometry to obtain a more precise knowledge of the isotopic composition of the elements. He developed a new instrument having higher resolution than previously available for such studies and undertook the determination of accurate isotopic abundances for five elements, namely argon, potassium, zinc, rubidium, and cadmium. In this work he discovered a rare isotope of potassium, ^{40}K, which later became important in the measurement of geological ages, a topic that reappears later in this memoir.

AT HARVARD (1936-38)

Al's thesis work attracted the attention of Professor K. T. Bainbridge of Harvard, who with E. B. Jordan had designed and constructed a mass spectrograph for precise determination of atomic masses. Bainbridge felt that Al's work on isotopic abundances would complement his own work. The award to Al in those frugal times of one of the coveted National Research Council fellowships and a $5,000 grant from Harvard's Milton Fund—a huge sum for a young researcher during the Depression—stimulated him to accept Bainbridge's invitation to come to Harvard, where he constructed a mass spectrometer superior to any he had used before, and to spend two memorable years there. During his Harvard fellowship Al studied the isotopic composition of nineteen elements and discovered four new isotopes. Of greater importance, however, were his studies of the isotopes of uranium and lead, heavy elements that his improved mass spectrometer could for the first time analyze readily. The work greatly advanced the infant subject of geochronology. His accurate measurements of the isotopic ratio $^{235}U/^{238}U$ bore on the uranium-lead method of dating of minerals where the ratio was of direct importance and indirectly so because it afforded better values of the uranium decay constants. While at Harvard Al began measuring the isotopic composition of various lead ores—so-called common lead as opposed to the isotopically very abnormal leads extracted from uranium and thorium minerals—which had become available to him chiefly from Professor G. P. Baxter of the Harvard chemistry department. These measurements, published in 1938, were used in landmark papers written in the mid-forties by F. G. Houtermans in Switzerland and Arthur Holmes in Great Britain to derive the first conceptually valid if not yet accurate values for the age of the earth. In his final weeks at Cambridge, Al made some of the first carbon isotope measurements, establishing that the ratio $^{13}C/^{12}C$ varies in nature—the basis for an entire field in modern isotopic geochemistry.

PRE-WAR YEARS AT MINNESOTA (1938-40)

Loyalty to his Minnesota mentors and concern for his aging parents led him to return to Minnesota and to join the physics faculty in 1938. "My sister died when I was young and my parents were old enough to be my grandparents," Al once said. "They were alone here." The return to Minneapolis in no way lessened Al's scientific productivity. The years 1938 to 1942, when he was free to pursue basic science, were described by his close friend and colleague Edward P. Ney as a "whirlwind of activity wherein he brought Minnesota to the forefront of isotope research." In this brief span of time a list of his results includes further development of the uranium-lead and thorium-lead methods for dating rocks and minerals; building a thermal diffusion column for the separation of carbon isotopes, thereby establishing collaborations with scientists who could, with him, use ^{13}C tracers to investigate a host of biochemical processes; further studies in neon and methane of thermal diffusion; and demonstration by the instruments constructed in his laboratory that sector magnets could replace, without loss of resolution, the 180-degree magnetic configurations he had used earlier. The resulting practical simplifications of sector-field instruments had much to do with the explosive replication of Nier-type mass spectrometers throughout science and industry worldwide.

Perhaps his most important discovery in those times (certainly the most spectacular, to use his own words) was the isolation of ^{235}U in 1940 and the proof that it was the uranium isotope that underwent fission for neutrons of all energies, including thermal neutrons. A classic paper by Bohr and Wheeler anticipated the result, but Enrico Fermi wanted experimental proof. Fermi and Al met at a meeting of the American Physical Society in 1938. Fermi later wrote a famous "Dear Nier" letter encouraging him to separate a small sample of pure ^{235}U for study of its fission properties. Within a very short time, considering the difficulty of this unprecedented task, Al made the first uranium isotope separation in history, using one of his mass spectrometers. He sent the submicrogram quantities of separated isotopes, fastened by their aluminum backings with Scotch tape in a covering letter, to John Dunning at Columbia. Dunning, Eugene Booth, and Aristid von Grosse repaired to the Columbia cyclotron that very evening and were able to show in a few hours that the 235 sample, and not the hundredfold more abundant 238 sample, was the source of the slow neutron fission in uranium. The certainty of this result undergirded the remarkable history of the Manhattan Project and the development of nuclear energy. Some might have belittled this experiment because of its simplicity and how quickly it was carried out, but it is doubtful that anyone else in the world could have done the job in anything like his swift and faultless manner. All of Al's talents came together to advance the work. The short account of the work, which appeared in 1940 in the *Physical Review,* essentially brought down the curtain on open publications about nuclear fission until the Smyth report appeared after World War II.

THE WAR YEARS (1942-45)

During the war years, Al's talents were diverted to applied research of great importance to the national effort. In the early development of large-scale separation of uranium isotopes, his laboratory was uniquely able to measure uranium isotopes, and he and a few students like Mark Inghram and Edward Ney were impressed into the task. Eight of the Nier instruments were later dispatched to other sites. Inghram took two instruments to Columbia; Ney took two instruments to the University of Virginia. Later on, for the vast isotope separation effort at Oak Ridge to succeed and to be safe, literally thousands of precise isotopic analyses of uranium samples were required. Al directed the required instrument development for the Kellex Corporation in New York City from 1943 to 1945. A prototype instrument of Nier design was sent to the General Electric Company, where hundreds of them were replicated and sold to the Manhattan Project. Along with the analytical instruments, Al designed a practical and portable helium leak detector of crucial importance in the gaseous diffusion plant.

RETURN TO MINNESOTA (1945-94)

At war's end, Al returned to Minneapolis and to a program of basic research, which flourished without interruption until the last two weeks of his life, when he was tragically hospitalized in almost total paralysis after losing control of his automobile and hitting a tree. He found or made time to chair the Physics Department at Minnesota for twelve years (1953-65), was a stimulating classroom teacher, and served his profession on numerous boards and committees, but his true love was working with research students in his laboratory. At this point in our account, rather than proceed chronologically, we look at some of the main chapters of his research.

GEOCHRONOLOGY AND ISOTOPIC GEOCHEMISTRY (1946-62)

He never lost interest in the subject of geochronology to which he had contributed so importantly during his years at Harvard and immediately thereafter. An increasing understanding of the processes by which the heavier elements formed suggested to C. v. Weizsächer and others that there was a causal relationship between the underabundance of ^{40}K (the rare isotope of potassium discovered by Al in 1935) and the overabundance of ^{40}Ar in the atmosphere. In 1948 with L. T. Aldrich, Al examined the isotopic composition of argon extracted from potassium minerals and discovered an excess there of ^{40}Ar, proving that ^{40}K was weakly radioactive and decaying, at least in part, to ^{40}Ar. With the basis for the potassium-argon dating method thereby conceptually established, its development ensued rapidly in laboratories throughout the world, including Al's, where H. Baadsgard and S. S. Goldich participated in the studies. Around 1950 Aldrich moved to the Department of Terrestrial Magnetism of the Carnegie Institution and established there a geochronology laboratory, which played a prominent role in the development of the rubidium-strontium dating method. Aldrich's colleagues in turn left Washington to establish other sites for geochronological work. In like manner Mark Inghram, whose interactions with Al was mentioned earlier, settled after the war in Chicago and supported work on geochronology, among other research topics. From that laboratory, students Clair Patterson, George Tilton, John Reynolds, Gerald Wasserburg (later a Crawfoord Prize awardee), and George Wetherill moved on to establish their own "shops." In this way one can categorize a large part of the worldwide geochronological effort as a pyramid of workers with Al at its apex. The Nier pyramid would be all encompassing with respect to geochronologists, if using magnetic sector instruments were the defining category, which is much the case.

Al and Aldrich also turned their attention to the scarce ^{3}He isotope. Their first paper on the subject investigated the difference in the ^{3}He/^{4}He ratio between the atmosphere and samples of well helium where ^{3}He is relatively rare because of pure ^{4}He production by alpha-decay of uranium and thorium and their radioactive decay chains. Helium studies of this kind have become another important subfield of isotopic geochemistry. It was discovered by others in 1969 that excess ^{3}He tags material derived preferentially from the earth's mantle so that isotopic studies in helium have since done much to elucidate mantle-crustal processes. Other helium papers by Al and Aldrich describe methods for enrichment of ^{3}He by thermal diffusion and by cryogenic techniques involving liquid helium. The cryogenic papers resulted from a collaboration between Minnesota and J. G. Daunt, Henry A. Fairbank, and others at Yale. A totally different helium investigation arose in Al's laboratory from the discovery elsewhere that iron meteorites contain highly isotopically anomalous helium as the result of spallation reactions induced in the iron by cosmic ray particles and that, because of shielding, depth effects occur. With John Hoffman, and later with Peter Signer, Al developed a program of investigation of helium and other noble gases produced by cosmic rays in meteorites, studies that contributed a valuable chapter in meteoritics. One can surmise that these were the researches that stimulated Al's interest in space physics, to which he made strong contributions later on, and in the Meteoritical Society, whose meetings became the favorite forum for his experimental studies after "retirement."

MASS MEASUREMENTS OF NUCLIDES (1951-63)

Al embarked on this journey in typical Nier fashion by designing a new instrument, namely a double focussing mass spectrometer as opposed to the double focussing mass spectrographs, which came earlier. (The term double focussing refers to the fact that a combination of electric and magnetic analyzers can be arranged so that both the angular and velocity spreads of ions emerging from a source can be brought simultaneously to focus at the final detector. Only double focussing can provide the very high resolution required if precise mass measurements are to be made. The difference between a mass spectrometer and a mass spectrograph refers to the mode of ion detection employed—photographic plates in the case of the spectrograph versus electrical detection in the spectrometer.) In either case the mass of the "unknown" ion is determined from its separation in a doublet occurring at the same mass number with a standard ion, usually a hydrocarbon fragment. Nier's instrument could display these doublets continuously by electrical means, whereas in the spectrographs a "blind" exposure would have to be made and be followed by removal of a photographic plate from the vacuum system for development and measurement. The Nier instrument was highly sophisticated, employing a second, single-focussing spectrometer tube as a means of regulating and, by ingenious circuitry, sweeping the relevant mass region to record the doublet. The final measurement of $\Delta M/M$ was reduced to resistance measurements of $\Delta R/R$ for a wire-wound potentiometer. Al developed and used this instrument with T. L. Collins, Walter H. Johnson, Jr., Tom Scolman, Karl Quisenberry, Clayton Giese, and others. Typical of Al's ideas about design, the first double-focussing instrument used a 6-in.-radius magnetic sector similar to those employed in his successful isotope mass spectrometers. The success of the first instrument led to other improved designs and finally to an instrument about 2.5 times larger than the original. With a magnetic radius of 16 in. and an ion path of about 10 feet, this was Al's largest instrument construction. Over the period from 1956 to 1979, this instrument was employed to measure the masses of almost all of the stable nuclides in the periodic table.

It is a remarkable fact that the accepted values for the masses of the stable nuclides (and thus their binding energies) now in the tables of nuclear data are predominately those determined by Al, despite the field having been highly competitive in its heyday. An explanation of this has to do with Nier's dislike and avoidance of extremely large construction projects. His taste ran to tabletop apparatus, where the construction resulted from interaction of the researcher with a few artisans from the departmental shops. In principle the resolving power of a mass spectrometer depends almost wholly on the inverse ratio of a slit width to a characteristic radius of the ion orbits in the machine. Most of Nier's competitors chose then to design and construct instruments of very large radius. The problem was that in the large instruments various effects, which had been of negligible disturbance in the table-top apparatus, proved troublesome as the dimensions were scaled up. So, instead of "surfing" through the isotope tables and defining the energy surface for nuclides with new precision, Al's competitors were struggling to build very large pieces of equipment and to solve the new problems that came with their size. Like all generalizations this explanation for Al's success in the field is an oversimplification, but no one can question his good judgement in choosing experimental approaches.

The community of mass measurers, although competitive, was a friendly one. H. E. Duckworth, one such competitor, spoke at Al's memorial colloquium in 1994 and commented on the friendly cooperation he had enjoyed with Al while they served together on the Commission on Atomic Masses of the International Union of Pure and Applied Physics. Duckworth also mentioned that it was Al and A. Ölander from Sweden who independently suggested to J. Mattauch in 1956 that the chemical atomic weight scale based on O = 16 and the physical atomic weight scale based on $^{16}O = 16$ be brought together in a unified scale with ^{12}C as the standard, a change that disturbed the chemical atomic weights very little but solved a myriad of problems that followed from the less appropriate (and different) oxygen standards. The international unions for both physics and chemistry adopted this unified standard in 1960.

UPPER ATMOSPHERIC AND SPACE PHYSICS (1964-85)

Al entered space physics with a bang in 1964. His former student J. H. Hoffman had moved on to the E. O. Hurlburt Center for Space Research at the Naval Research Laboratory and their joint interest in applying their skills in mass spectrometry to problems in upper atmospheric physics led to a collaboration between the two laboratories. The first papers from this partnership appeared from 1964 to 1966. By 1985, as part of the growing involvement of the Minnesota department in space physics (e.g., by the work there of Robert Pepin, Jeff Hayden, and Konrad Mauersberger), more than fifty papers in space physics had appeared with Nier as an author.

Reading the first of these papers and knowing Al's enthusiasm for new research topics, one can easily sense his excitement. He was still using familiar instruments of his own construction, but now he had the novelty of hunching down in a bunker "where the clocks ran backwards and all that," while his mass spectrometers went blasting off into new territory. The first successful flight incorporated two mass spectrometers, one of which burned out a filament and simply went along for the ride, but the other worked perfectly. Reading about it, one shares his delight in how the mass spectrum of the neutral species in the upper atmosphere were modulated by the rolling of the rocket, leading to big signals when the motion of the rocket was "toward the air" and small signals when "away from it." With collaborators he was able to analyze this effect in detail and among other things deduce the temperature of the atmosphere as a function of altitude between 120 and 200 kilometers where the data were recorded.

Al directed much of his efforts in space physics to overcoming the problem that chemically active species, such as atomic oxygen and nitrogen, although present in the upper atmospheres of planets in concentrations that are important to know, interact quickly with surfaces of the instruments for their detection. He made the valuable discovery that in his open-source mass spectrometer, where the Nier ion source is exposed directly to the atmospheric particles that stream into the moving spacecraft, minor changes in the voltages applied to the electrodes enabled the instrument to discriminate strongly in favor of particles that had not impacted with surfaces of the instrument before entering the ionizing region. Thus, again his familiar spectrometers could play an important role in studying the neutral particles in planetary atmospheres. As early as 1973 he was reporting results from flying his mass spectrometers in satellites.

Major participation in the Viking missions to Mars provided the capstone of Nier's work with mass spectrometers in space. From the beginning, with Harvard's M. McElroy, he had responsibility for planning and executing the elemental and isotopic measurements of the Martian atmosphere during the descent of the spacecraft. Some of the most important discoveries of the Mars missions came from this work. Most notable was the discovery that nitrogen in the Martian atmosphere is strongly fractionated, such that the rare heavy isotope ^{15}N is enhanced by 62% with respect to the $^{15}N/^{14}N$ ratio in the earth's atmosphere. Two important lines of research stem from this discovery. In the first place, it is a pivotal fact in understanding the history of the Martian atmosphere that the fractionation almost certainly arose from preferential escape of the light isotope ^{14}N and the datum provides an important boundary condition. Second, the anomalous nitrogen Al found on Mars has been a crucial and clinching piece of evidence that a small subset of meteorites in our collections originated on the Martian surface. D. D. Bogard and P. Johnson at the National Aeronautics and Space Administration's (NASA) Johnson Space Center first saw the possible connection through comparing elemental and isotopic abundances of the noble gases in one such meteorite with values found by Nier in the Martian atmosphere. Later analysis of nitrogen and other gases from the putative Martian meteorites by R. O. Pepin, R. H. Becker, and R. C. Wiens in Nier's own department at Minnesota, together with experiments on shock implantation of ambient gases in suitable materials by Bogard and F. Hörz, and by Wiens, proved the hypothesis of Martian origin.

At the request of high-level management at NASA, Al was a late addition to another of the Viking experimental teams, namely the one responsible for the gas chromatograph mass spectrometer on the Viking landers. This highly complex instrument, which included mass spectrometer detection, could analyze volatile products from heating of Martian soil samples, important in the search for organic substances on the planet. It could also build up measurable samples of inert constituents of the atmosphere by processing multiple "gulps" of the predominant CO_2 there. Al's involvement came about because inspectors recognized serious problems with the instrumentation when little time remained for their correction. Al, who was much experienced in miniaturizing instruments for flight, enlisted A. E. Cameron from the Oak Ridge National Laboratory as a coworker and between these "old hands" at mass spectrometry things were fixed. Al with characteristic modesty downplayed their role. Those close to the matter, however, saw their participation as crucial for the program's final success. The most important science from the lander came from the revised instrument. Al went on from his Viking triumphs to participate in measurements of the atmosphere of Venus.

NOBLE GAS MICROANALYSIS (1983-94)

Retirement from research was never an option with Al. Retired only in other respects, he created the perfect program for his last years in the laboratory. His work in space physics had led him to delight in the construction of miniaturized mass spectrometers with high performance. In his space physics years he would come to NASA meetings carrying what looked like an ordinary attaché case. Ordinary it was not; when opened it proved to be a functional mass spectrometer, which he would turn on and proceed to analyze the room air. How better could he convince NASA officials that his instruments should fly on missions to deep space? A refined laboratory version of this spectrometer was the perfect vehicle for Al's late work with a gifted technician, D. J. Schlutter. Needing only modest levels of financial support, they undertook studies of the noble gases in individual interplanetary dust particles, sometimes called Brownlee particles after Don Brownlee, who pioneered in capturing these stratospheric particles and showing which ones were extraterrestrial. His contributions to this new field of study of extraterrestrial material were so important that a major concern at his death was whether others would continue the research. Fortunately, R. Pepin has continued the work with Schlutter and, in tribute to Al's good judgement in choosing research topics, has seen it explode in scope as various other microsamples, such as small lunar and meteoritic mineral grains, come under scrutiny.

NIER AS A PERSON

A frequent description of Al is, "the most refreshing scientist I have ever met." He had not an ounce of pomposity in his makeup. His curiosity and enthusiasm for scientific work were boundless and unmatched. He was competitive but only in the sense that, once setting himself a scientific goal, he applied his characteristic energy and self-confidence to reach that goal as quickly as possible. Once there, he never overstated his results. His measurements invariably stood up within their quoted uncertainties. He freely described and published how he did things. He considered "instrument papers" just as important as those giving results. He had full respect for the talents of the artisans with whom he worked in developing new tools for research. His joint publications with R. B. Thorness, a master machinist with whom he frequently collaborated, are a case in point. The relationship between Al and "Buddy" Thorness was very fruitful and very deep. The respect and consideration that Al had for the "shop" and the skilled and dedicated individuals who worked there was a symbol of the fruitful old system in which experimental physics was greatly advanced by dedicated staff and universities provided facilities as a matter of course.

Al was an enthusiastic traveler. He developed to a fine art the techniques for traveling "light" to a distant meeting and presenting his results. He usually knew about quick-dry clothing and compact slides and cameras (he was never without one) before the rest of us. His picture taking was a good key to his personality. He was usually the most distinguished scientist in a group, one who might fittingly stand aside for others to "shoot." But it was he who carried the camera, organized the group photo, and passed his camera on to others at the end so that the rest of us would be in a picture with him. One travel trick comes to mind. He would carry a set of preaddressed labels with him for the postcards he intended to send. "You can tell by how many stickers are left," he explained, "whether or not you are doing your job." Enjoyment of travel was not a singular appetite. He enjoyed all aspects of his busy life. Travel was just one of the things he relished, which we necessarily witnessed if we went to the same meeting.

Al was married twice and must have felt pain when he and Ruth, the mother of his children, parted company. He was fortunate in that Ardis shared with him his last twenty-five years of exceptional happiness and contentment. Al was very proud of his children, Janet Marx of Springfield, Virginia, and Keith Nier of Madison, New Jersey, and four grandchildren. Ardis has continued a close relationship with them.

Al was awarded many honors for his work. He received the Arthur L. Day Medal of the Geological Society of America, William Bowie Medal of the American Geophysical Union, Victor Goldschmidt Medal of the Geochemistry Society, and the Field and Franklin Award of the American Chemical Society. He was elected to the National Academy of Sciences, American Philosophical Society, and American Academy of Arts and Sciences. His foreign honors included election as foreign scientific member of the Max-Planck Institute for Chemistry in Germany and the Royal Swedish Academy of Science. He was honored by the Atomic Energy Commission and by NASA for contributions to government science programs. We mentioned earlier his honorary doctorate of science from the University of Minnesota. An honor, which he enjoyed repeatedly (and his friends frequently apprised him of), was to have the clue "American physicist" appear in the *New York Times* crossword puzzle. He modestly dismissed this evidence of fame by pointing out that four-letter words with two vowels are much needed in such puzzles.

In addition to honors awarded to him directly, there are many honors that were given to his scientific "descendents," awardees who frequently acknowledged their debt to the facilities Nier invented and the example he set in their use. The respect and affection of those in the Nier pyramid are his most significant and lasting honors.

THE AUTHOR WISHES to thank reviewers W. H. Johnson, Jr., K. Mauersberger,

R. O. Pepin, and G. J. Wasserburg for critical attention to the manuscript and valuable suggestions.

REFERENCES

Alfred Otto Carl Nier, American physicist. In *Modern Scientists and Engineers,* pp. 361-63. McGraw–Hill, 1980.

Autobiographical sketches in the files of the National Academy of Sciences written in June 1950 and November 1990.

Duckworth, H. E. and G. J. Wasserburg. Remarks at Nier Memorial Colloquium, Nov. 2, 1994.

Moore, M. P. 1991. Alfred O. C. Nier: Physicist-gadgeteer extraordinaire. *Univ. Minn. Res. Rev.* April.

Ney, E. P. Unfinished Nier memoir, 1995-96.

Obituary. *Minneapolis Star Tribune,* May 17, 1994.

Obituary. *St. Paul Pioneer Press,* May 17, 1994.

Pepin, R. and P. Signer. 1994. Memorial: Alfred O. C. Nier (1911-1994). *Meteoritics* 29:747-48.

Rokop, D. R. Dedication. In *Proceedings of the Alfred O. Nier Symposium on Inorganic Mass Spectrometry, May, 1991, Durango, Colorado.* Los Alamos National Laboratory Conference Report LA-12522C (UC-401 and UC-410) May 1993.

SELECTED BIBLIOGRAPHY

1935

Evidence for the existence of an isotope of potassium of mass 40. *Phys. Rev.* 48:283-84.

1937

A mass spectrographic study of the isotopes of Hg, Xe, Kr, Be, I, As, and Cs. *Phys. Rev.* 52:933-37.

1939

The isotopic constitution of uranium and the half-lives of the uranium isotopes. I. *Phys. Rev.* 55:150-53.

The isotopic constitution of radiogenic leads and the measurement of geological times. II. *Phys. Rev.* 55:153-63.

With E. A. Gulbransen. Variations in the relative abundance of the carbon isotopes. *J. Am. Chem. Soc.* 61:697-98.

1940

With others. Nuclear fission of separated uranium isotopes. *Phys. Rev.* 57:546.

A mass spectrometer for routine isotope abundance measurements. *Rev. Sci. Instrum.* 11:212-16.

1941

With B. F. Murphey. Variations in the relative abundance of the carbon isotopes. *Phys. Rev.* 59:771-72.

With others. The isotopic composition of lead and the measurement of geological time. III. *Phys. Rev.* 60:112-16.

With J. Bardeen. The production of concentrated carbon 13 by thermal diffusion. *J. Chem. Phys.* 9:690-92.

1947

A mass spectrometer for isotope and gas analysis. *Rev. Sci. Instrum.* 18:398-411.

With others. A new method of separation of the isotopes He^3 and He^4. *Phys. Rev.* 72:502-3.

1948

With L. T. Aldrich. Argon 40 in potassium minerals. *Phys. Rev.* 74:876-77.

1950

Redetermination of the relative abundances of the isotopes of carbon, nitrogen, oxygen, argon, and potassium. *Phys. Rev.* 77:789-93.

1951

With T. R. Roberts. The determination of atomic mass doublets by means of a mass spectrometer. *Phys. Rev.* 81:507-10.

1957

With W. H. Johnson, Jr. Atomic masses in the region xenon to europium. *Phys. Rev.* 105:1014-23.

1960

With P. Signer. The distribution of cosmic-ray produced rare gases in iron meteorites. *J. Geophys. Res.* 65:2947-64.

1964

With others. Neutral composition of the atmosphere in the 100- to 200-kilometer range. *J. Geophys. Res.* 69:979-89.

1971

With J. L. Hayden. A miniature Mattauch-Herzog mass spectrometer for the investigation of planetary atmospheres. *Int. J. Mass Spectrom. Ion Phys.* 6:339-46.

1972

With others. Entry science experiments for Viking 1975. *Icarus* 16:74-91.

1973

With others. The open-source neutral-mass spectrometer on Atmosphere Explorer-C, -D, and -E. *Radio Sci.* 8:271-76.

1977

With M. B. McElroy. Composition and structure of Mars' upper atmosphere: Results from the neutral mass spectrometers on Viking 1 and 2. *J. Geophys. Res.* 82:4341-49.

1979

With others. Venus thermosphere: In situ composition measurements, the temperature profile, and the homopause altitude. *Science* 203:768-69.

1987

With others. Helium and neon isotopes in extraterrestrial particles. Abstracts of the 18th Lunar and Planetary Science Conference, pp. 720-21.

1994

With D. J. Schlutter. Helium and neon in lunar ilmenites of different antiquities. *Meteoritics* 29:662-73.