



GERHARD HERZBERG

became leaders in their specialty branches. Distinguished scientists and postdoctoral fellows from around the globe came to work at the lab, which was so successful that it was cited at the Nobel awards ceremony as the undisputed center for molecular spectroscopy. Herzberg remained at the NRCC in Ottawa until he retired in 1994.

Here we can summarize only some of the highlights of Herzberg's 70 years of active research. His main contributions to atomic physics include fundamental problems, such as the nuclear spin of nitrogen-14 and helium-3 and Lamb shifts in the ground states of deuterium, He, and Li^+ .

During their time together in Darmstadt, he and Heitler concluded, from the alternation of intensities in the rotational Raman spectrum of molecular nitrogen, that ^{14}N had integer spin and followed Bose statistics. That was in 1929—three years before the discovery of the neutron and at a time when the N nucleus was thought to have an odd number of fermions (14 protons and 7 electrons) and to follow Fermi statistics.

Other early contributions included a seminal paper with Edward Teller on the theory of vibrational intensities in electronic transitions (1933), the recognition that molecular bond lengths depend on the nature of neighboring bonds (1937), and determinations of the dissociation energies of the molecules O_2 , C_2 , and H_2 .

Following a meeting at Yerkes in 1941 and discussion with Teller, Herzberg and Alexander Douglas identified three previously unknown spectral lines as being due to CH^+ by reproducing the spectrum in the laboratory at Saskatchewan. This was the first interstellar molecular ion to be discovered and one of only three interstellar

molecules to be identified before the wave of identifications by radio astronomy that began with the OH radical in 1963 and the NH_3 molecule in 1968.

One of the fruits of Herzberg's Yerkes sojourn was the laboratory observation of the infrared absorption spectrum of H_2 due to the electric quadrupole moment of the molecule. This spectrum, which was subsequently observed in emission in Jupiter, Saturn, and Uranus, provides a powerful means to study the hot gas in objects such as planetary ionospheres, circumstellar atmospheres, planetary nebulae, and superluminous galaxies. Herzberg was also the first to discover, in 1952, extraterrestrial H_2 in Uranus and Neptune by reproducing planetary pressure-induced spectra of H_2 in the laboratory.

In the early 1950s, Herzberg developed and applied flash photolysis. In this technique, parent molecules are split by intense pulses of light into short-lived fragments whose absorption spectra are recorded on a photographic plate. The technique's high sensitivity led to the discovery at the NRCC of the spectra of a number of important free radicals—including, NH_2 , HCO , CH_3 , CH_2 , C_3 , and BH_2 , of which CH_3 and CH_2 are particularly important in organic chemistry.

In 1963, Herzberg and Christopher Longuet-Higgins published a paper on the adiabatic electronic wavefunction's change of sign—an early example of a geometric phase—which occurs when the wavefunction is transported round a point of degeneracy.

For much of his career, Herzberg was fascinated by the diffuse interstellar bands, whose source had long been an enigma to observational astronomers. He was a strong proponent of the idea that the bands are due to molecules in the gas phase, an idea initially down played in preference to interstellar dust grains, but now gaining acceptance as more observations are made.

Since his earliest work on hydrogen, Herzberg had hoped to find the emission spectrum of H_3^+ , whose observation in the laboratory would be an invaluable tool in the search for H_3^+ in the interstellar medium. Instead, in 1979, he found the spectrum of neutral H_3 . In this electron recombination spectrum, a positive ion picks up an electron and then cascades down through the Rydberg states to the ground state, which is unstable and falls apart. Herzberg's original goal, the spectrum of H_3^+ , was found by one of us (Oka, who was in Herzberg's group at the time), and has recently been observed in molecular clouds and the diffuse interstellar medium.

From 1969 to 1994, birthday conferences were held every five years to celebrate Herzberg's friendship and achievements. The unwavering enthusiasm of the participants was evidence of the continuing vigor of the various branches of science to which Herzberg had contributed so much. At the first of those conferences, his appointment as Distinguished Research Scientist at NRCC was announced, and at the next, the creation of the Herzberg Institute of Astrophysics at NRCC. Though he received many awards, medals and honorary degrees during his lifetime, Herzberg was probably proudest of the spectroscopy laboratory he established in Ottawa in the late 1940s.

When the NRCC became a target for government economies, he was always ready to speak out against bureaucracy and in defense of basic science. He was also a strong advocate of the rights of dissidents in authoritarian countries.

In his prime, Herzberg was notable for the energy and excitement that he brought to his field, and he was an outstanding lecturer—clear, well-organized, and with a knack for choosing the right amount of detail. On a broad range of spectroscopic problems in physics, astrophysics, and chemistry, he brought to bear a keen and lively research interest and became a father figure for workers in the field of spectroscopy. This status was no doubt enhanced by his monograph, *Atomic Spectra and Atomic Structure* (still in print after 62 years), and by his three-volume *Molecular Spectra and Molecular Structure* (1939, 1946, 1966), which became the bible for researchers in the field.

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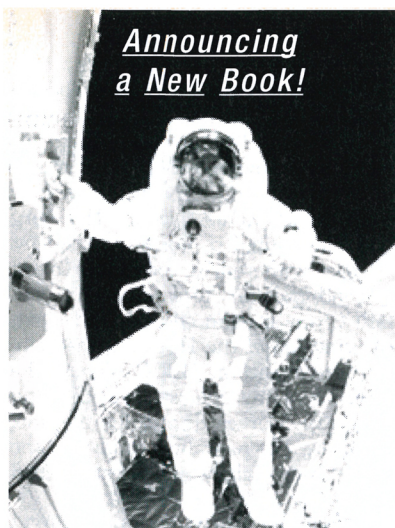
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Robert Green Sachs

Robert Green Sachs, a distinguished theoretical physicist and outstanding scientific administrator, died in Chicago on 14 April of complications following surgery.

Sachs was born in Hagerstown, Maryland, on 4 May 1916. He did both undergraduate and graduate work at Johns Hopkins University, where he went directly from two years of undergraduate study to the PhD program in physics. He earned his PhD in 1939 under the supervision of Edward Teller and Maria Goeppert Mayer for work



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After graduation, he became a postdoc under Teller, working on a wide range of problems in atomic, molecular, nuclear, and solid-state physics. Sachs's work at Johns Hopkins led to an instructorship at Purdue University and then to an invitation from J. Robert Oppenheimer to become his postdoctoral fellow at the University of California. Taking a leave of absence from Purdue, he moved to Berkeley and was gaining an introduction to meson theory when the Japanese attack on Pearl Harbor on 7 December 1941 turned Sachs, Oppenheimer, and nearly every other physicist in the US to new and unfamiliar tasks.

Sachs was called upon to serve as chief of the air ballistic section at the Ballistic Research Laboratory, located at Aberdeen Proving Ground outside Baltimore. His group analyzed tests of bombs and explosives to study the effectiveness of actual aerial bombing. Sachs is credited with providing the first assessments of the atmospheric blast waves from nuclear bombs, showing the dependence of the blast effects on ambient atmospheric conditions. This finding, and many of his other research results during the war years, were presented in classified reports. Some of that work did appear subsequently in regular journals. His work on relativistic shock waves, for example, proved to be important in theoretical astrophysics.

After the war, Sachs became the director of the theoretical physics division of the University of Chicago and Argonne National Laboratory's Metallurgical Laboratory. His responsibilities included recruiting theoretical physicists, designing reactors, and giving introductory lectures in a nuclear engineering training program at Clinton National Laboratory (later Oak Ridge National Laboratory).

In 1947, he joined the physics faculty at the University of Wisconsin, where he wrote his widely used text *Nuclear Theory* (Addison-Wesley) in addition to 36 papers, among which were several on nuclear photoprocesses and on the related topics of K-meson decay, *CP* violation, and time reversal. In 1964, he was called back to Argonne as associate laboratory director and to Chicago as a professor of physics.

His appointment as associate lab director came at a time of great controversy between the Atomic Energy Commission and the Midwest universities. To overcome the concern of the academic community about the prospects for open research at what had been a highly restricted research laboratory, a plan had been worked out for



ROBERT GREEN SACHS

formation and governance of a users group for the Zero Gradient Synchrotron, which was just then coming into operation. Sachs brought about a vigorous research program at the accelerator by his wise and effective implementation of what had been little more than a plan on paper.

From 1968 to 1973—and again from 1983 to 1986—he served as director of the Enrico Fermi Institute. From 1973 to 1979, he served as director of Argonne.

Despite the heavy load of administrative duties that he carried for many years, Sachs made wide-ranging contributions to nuclear and particle physics. His research was characterized by two cardinal principles. First, experiment is what defines physics—not pure thought or mathematics, regardless of how elegant and beautiful they may be. Second, the underpinning of a good theory should be the most general, well-established basic principles that provide a basis for phenomenological analysis.

Thus, a large body of his work was based on gauge principles in the study of electromagnetic interactions of nuclei. He introduced gauge-invariant exchange currents in phenomenological studies of nuclear forces and provided physical interpretation of electromagnetic form factors of the nucleons. The so-called Sachs mirror theorem for the magnetic moments of mirror nuclei established a correlation between the observed magnetic moments and the internal angular momentum structure of light nuclei. In the early days of particle physics, when many new particles were discovered, he proposed a classification scheme that paralleled the Gell-Mann–Nishijima scheme and went beyond that to include leptons. In 1962, he wrote a classic paper with Sam Treiman on time dependence of K–K bar

interference effects that served as a forerunner for a number of theoretical and experimental discoveries in K-meson physics.

A problem that occupied Sachs's central interest over many years was that of the violation of *CP* and time-reversal invariance. He began a series of important papers on the subject—even before the experimental discovery in 1964—and he continued to write on this subject until his death. He was keen on emphasizing the distinction between *CP* and *T* violation, which continues to get blurred. The ultimate origin of these symmetries and their violation was what directed much of his thinking on the subject. His most recent speculation, based upon a study of the structure of the quantum chromodynamics vacuum and the so-called strong *CP* problem, related the observed *CP* violation in the K-K bar system to a possible *T*-violating electric dipole moment of the neutron, and made a prediction for the latter that could be tested in the near future.

In 1987, he wrote a scholarly book entitled *The Physics of Time Reversal* (University of Chicago Press) about which he was particularly proud. For years, his office clock ran backward.

Outside the field of physics research, Sachs is noted for his contributions to questions relating to national and international energy policies, for his services on physics advisory panels, his active role in the National Academy of Sciences, and for creating the division of particles and fields of the American Physical Society.

Sachs was a wonderful colleague. He devoted himself to recognizing, supporting, and encouraging independent thinking, particularly in his younger colleagues. He frequently took on beginning graduate students for their first year, immersing them in the full range of theoretical physics before they went their specialized ways. It is a fitting tribute that the most promising of the entering graduate students in physics at Chicago are now honored with Sachs fellowships. We speak for all his colleagues and former students in expressing deep sadness at his passing.

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William Bernstein

William Bernstein, a former research professor at Rice University's department of space physics and



WILLIAM BERNSTEIN

astronomy, died on 6 March in Houston, Texas, of complications from quadruple heart bypass surgery.

Born in New York City on 26 June 1924, Bill earned a BS in physics at New York University in 1944. After the US entered World War II, he volunteered for the US Army, and served as a technical sergeant installing mountaintop radars in California. After the war, he undertook graduate work in nuclear physics at the University of Wisconsin in Madison. However, his PhD studies were curtailed when he had to attend to family business when his father died.

From 1948 until 1955, Bill investigated medical radiation problems at what was then the Brookhaven Laboratory. He then spent the next four years working on Project Matterhorn at Princeton University's Plasma Physics Laboratory, where he performed experiments associated with Martin Kruskal's theories.

Bill returned to Southern California in 1959 to continue research in plasma physics—this time, at the research laboratory of Hughes Aircraft Corp.

Having moved to TRW Systems in 1965, Bill led a team that fired one of the earliest Javelin rockets from Wallops Island, Virginia, to explore the upper atmosphere and ionosphere before, during, and after a total solar eclipse. These investigations, which took place on 6, 7, and 8 March 1970, included the first-ever direct measurements of the precipitation of energetic (about 10 keV) neutral hydrogen atoms into Earth's atmosphere.

Other rocket flights that Bill oversaw were launched from above the Arctic Circle and performed coordinated measurements of electrons, protons, electric and magnetic fields, and hydrogen Balmer-line emissions. Bill thoroughly enjoyed mounting these ex-

peditions, during which he picked up an interest in Inuit soapstone sculptures, as well as an aversion to wind-chill factors lower than -60°F .

At TRW, Bill was part of an informal group of plasma physicists who started a world-class effort to apply plasma theory to space and ionospheric physics. Maintaining his interest in fusion research, he made several sabbatical visits in 1964–65 to the Culham Laboratory in England.

Moving to NOAA's Space Disturbances Laboratory in 1971, Bill led a team that simulated the fundamental aspects of magnetosphysics. To continue that work, he took a position in 1980 as a research professor at Rice University.

These studies were conducted in large vacuum chambers, starting at NASA's Lewis Research Center's facility in Plum Brook, Ohio, in December 1974 and continuing in the 90-foot chamber at NASA's Johnson Space Center (JSC) in Houston. The results clarified aspects of electron beam behavior that arise when accelerated electrons interact with a weakly ionized plasma in a very low background pressure equivalent to the ionosphere's E-region and with a uniform magnetic field of 1.5 gauss. Previous work along this line had been performed only in laboratory fusion devices. During the first experimental run at JSC, Bill and his colleagues observed a beautiful beam-plasma discharge in the chamber that led to a thorough investigation of its onset conditions and associated steady state phenomena. Bill's successful direction of this project, which culminated in the publication of many papers, was perhaps his greatest accomplishment.

As a member of the research faculty at Rice, Bill advised a number of graduate students. A demanding adviser, he cared very deeply about their welfare.

Bill was a brilliant scientist, a concerned citizen, a man of broad culture, and a valued colleague. Despite his stern appearance, he was a very warm person who impressed everyone with his understanding and stimulating intellect. He wanted to learn more and believed in learning through research. A firm humanist, he had a lively interest in political and social issues and deeply held convictions on them.

We shall remember and miss him as a warm friend and colleague and as a superb and meticulous scientist.

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