Maurice Goldhaber

1911–2011

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Robert P. Crease
and Alfred S. Goldhaber

NATIONAL ACADEMY OF SCIENCES

MAURICE GOLDHABER

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(Courtesy of Brookhaven National Laboratory.)

M Goldhaber

BY Robert P. Crease
and Alfred S. Goldhaber

Maurice Goldhaber was an experimental nuclear physicist and scientific laboratory director. By a "happy coincidence," as he liked to say, he was born in the same year, 1911, the atomic nucleus was discovered. Further, he came of age the same year nuclear physics did, in 1932, when the discovery of the neutron laid the framework for that field, in which he was to be a pioneer. Maurice was especially imaginative at synthesizing apparently unrelated pieces of information about the nucleus—especially involving spin—to devise experiments unearthing new facts about it. He also devised several experiments that applied techniques of nuclear physics to shed light on key concerns of elementary particle physics. The two most notable of these were the photodisintegration of the deuteron, in 1934, which allowed a measurement of the mass of the neutron; and the determination of the helicity of the neutrino, in 1958, which contributed a key piece to the emerging picture of the weak interaction. Maurice also was known for giving talks that summarized the state of nuclear and particle physics, and for his witty apothegms that physicists still enjoy repeating. He was a patriarch of a family that includes three generations of physicists.

Upbringing and education: Lemberg, Chemnitz, and Berlin (1911-1933)

Maurice's great-grandfather Gershon Goldhaber was a rabbi. His grandfather Meshullam was a small merchant, and his father, Charles (originally Chaim), was a self-taught linguist, lover of Egyptology, entrepreneur, adventurer, and occasional tour guide whose economic status fluctuated but who always managed to support and care for his family.

In 1911 the town of Maurice's birth was called Lemberg, and it belonged to the Austro-Hungarian Empire. The city would change political hands several times in the century that followed, becoming part of Poland and then the Soviet Union; it is now called Lviv and lies in western Ukraine. Maurice (originally Moritz) himself underwent a series of dislocations. In June 1914 the family—Charles; his wife, Ethel; and three small children (the eldest was Leo, followed by Maurice and Friedl, while a fourth, Gerson, would be born in 1924)—was in or near Sarajevo when the Austrian Archduke Franz Ferdinand was assassinated there. Anticipating war and a military draft, and not feeling especially tied to a particular culture or geographical location, Charles took the family to Egypt, where he had long experience dating back to his teenage years, and settled in Alexandria, going into the Persian rug business. World War I broke out a month after the assassination, and the British authorities in Egypt declared Austrians to be enemy aliens. Pretending to be Russian, Charles managed to evade the authorities until 1916, when he was interned in a camp on the Mediterranean shore and the rest of the family was deported back to Austrian-held territory. They went to Markersdorf in Austria (now Markvartice in the Czech Republic). After the war, Charles was released and the family reunited, eventually moving to Chemnitz in eastern Germany, where Gerson was born. In Chemnitz, Charles joined his brother Jacob running a factory manufacturing stockings for export, an enterprise that helped assure the family's financial survival during the German hyperinflation of the early 1920s, though it would fail during the Depression.

In Chemnitz, Maurice attended the *realgymnasium*, the German equivalent of a science-focused high school. There he had nine years of Latin, seven of French, and five of English: the amounts were "in opposite order of usefulness," he liked to say. He also picked up some Italian from his parents, who spoke that language when they didn't want the children to understand what they were discussing.

At the *realgymnasium* Maurice considered a career in engineering and mathematics before deciding on physics. In 1930 he received his Abitur, or graduation certificate. Graduates could attend whatever university they pleased, and Maurice headed for the University of Berlin where many notable physicists—Max Planck, Albert Einstein, Max von Laue, Walther Nernst, Erwin Schrödinger, Otto Hahn, and Lise Meitner—could be found at the weekly physics colloquium. In later years Maurice liked to recall Einstein, Nernst, Planck, Schrödinger, and Meitner all sitting in the front row, with Nernst asking most of the questions and Planck and Einstein sitting mainly in silence.

Maurice spent three years at the University of Berlin. He found Meitner's pioneering course on Kernphysik—nuclear physics—especially stimulating, and took von Laue's proseminar, in which students were asked to read and report on assigned papers. In that course he met his future wife, Gertrude ("Trude") Scharff, who had begun her physics studies in Munich also in 1930 and then spent several semesters at other universities, culminating in her stay in Berlin during spring 1932. Conceiving himself as a theoretical physicist, Maurice discussed possible thesis topics with Schrödinger.

In January 1933 Hitler came to power, beginning a tumultuous time for Germany and the university. Almost immediately Charles, who again felt few ties to Germany, took the family members still in Chemnitz (his wife, Ethel, and sons, Leo and the young Gerson) back to Egypt. He wrote to Maurice that he should leave Germany as quickly as possible, giving the same advice to his own brother Jacob and members of the extended family.

On one occasion a pro-Nazi rally in Berlin caused all lectures to be canceled. Maurice sought refuge in the library and perused popular science journals. From one he learned the news that the physical chemist Gilbert N. Lewis, of Berkeley, had managed to produce almost a cubic centimeter of heavy water, that is, water with heavy hydrogen, whose nucleus (then called a diplon and now a deuteron) contains not only a proton but also a neutron. The news astonished him because this was such a large quantity of such a rare form of matter. "I immediately asked myself: To what use could heavy hydrogen be put?" (1979, p. 84). One of his ideas was based on the notion that there might be a loose analogy between diplons/deuterons and hydrogen atoms. In hydrogen atoms electrons occupy different energy states about the proton. If the atom absorbs enough energy, the proton and electron can be entirely separated in a process known as the photoelectric effect, or photodisintegration. Suppose protons and neutrons behave similarly, Maurice mused, might you be able to separate proton and neutron?

Maurice, however, was also paying attention to his father's advice to leave Germany but felt that to leave Berlin he needed to be accepted elsewhere as a student. A confident and ambitious 22-year-old, he wrote letters to the three most famous physicists outside Germany—Niels Bohr in Copenhagen, Wolfgang Pauli in Zürich, and Ernest Rutherford in Cambridge—asking to be accepted as a student. Schrödinger wrote recommendations to all three for Maurice, saying that Maurice "has proved to be a very assiduous and intelligent student."[1]

Rutherford was the first to reply. Maurice immediately got a visa and left in May 1933 before the semester was out. He took the train to Holland to visit his cousin—Jacob's daughter Regina, along with her husband and three children—then caught the boat to England. Uncle Jacob and his wife, Dora, did not leave until 1936, taking refuge in Amsterdam with Regina and her family. During the war, they all died in the Holocaust, as did almost all Maurice's many uncles, aunts, and cousins on his mother's side, but amazingly none of his immediate family members perished.

"The Age of Innocence" in nuclear physics: The Cavendish years (1933-1938)

The Cavendish was then the foremost nuclear physics laboratory in the world. Ernest Rutherford, its director, had discovered the alpha particle in 1899, the atomic nucleus in 1911, and the proton in 1917 (in the first deliberate nuclear transformation). The immediately previous Cavendish professor of experimental physics, J. J. Thomson, had discovered the electron in 1897. The Cavendish assistant director of research, James Chadwick, had discovered the neutron in 1932. This last finding completed the discovery of the basic constituents of the atom and opened the door to the golden years of nuclear physics: the systematic investigation of different kinds of nuclei, their various forms and shapes, and their properties and behaviors.

These were years of innocence. The nucleus was known to contain energy, yes, but the prospect that this energy could be released in other than minuscule amounts seemed so preposterous that Rutherford himself famously called it "moonshine." Nuclear physics was a vibrant and productive field, tremendously rewarding to those like Maurice who were imaginative and inventive.

Maurice found Cambridge a warm and welcoming place. The presence of many German refugees made it socially comfortable; indeed, Maurice found himself speaking altogether too much German, which slowed his quest to perfect English. To earn money he tutored, with one of his pupils being a young American physics student named Norman Ramsey. The Cavendish workplace was also a relaxed environment. Rutherford shut the lab at 6 p.m., to curtail the kind of obsessive workaholic behavior that, he felt, interfered with creativity. "In those days one didn't yet feel the hot breath of competition, certainly not at the Cavendish," Maurice later recalled. "It was possible to have an idea that one thought important, to sit on it for a year or so without being afraid of losing it, and if it was lost nevertheless, to say to oneself, "Now I can go on to the next idea" (1979, p. 86).

Rutherford was away when Maurice first visited the Cavendish, in August 1933, but Chadwick took Maurice under his wing. He urged him to join a college, and as a result Maurice wound up at Magdalene. When Rutherford returned in the fall, he assigned Maurice, who continued to conceive himself a theorist, to work with Ralph Fowler, a Cavendish theorist and Rutherford's son-in-law.

One of Maurice's earliest research topics concerned nuclear reactions involving lithium isotopes. Three reactions had been studied, but counter to expectations the one that released the most energy occurred at the smallest rate. Maurice proposed that spin was a factor, but if so, he conjectured in synthesizing the available bits of information, the spin of ^{6}Li was not 0 as thought but likely 1 (1934, 3). The conjecture turned out to be correct. This illustrated a hallmark of much of Maurice's subsequent research: his ability to use a synoptic knowledge of seemingly unrelated nuclear properties to devise ways to uncover further information.

While consulting with Chadwick about the masses of the lithium isotopes, Maurice gathered the courage to mention his idea about the photodisintegration of the diplon. The idea looked experimentally feasible, given the recent discovery of a particularly powerful gamma ray in radioactive material possessed by the Cavendish. The idea had also occurred to several other physicists at the time, including Leo Szilard at nearby Oxford. Chadwick seemed interested when Maurice mentioned that such an experiment might provide an accurate measurement of the neutron's mass, but in the end appeared to Maurice diffident about the project. Maurice found this surprising, for the neutron's mass was still unknown and bore on the identity of the neutron itself. While the mass of the proton and deuteron had been measured, the binding energy of the deuteron had not, and it was not even sure whether the deuteron was a simple combination of proton and neutron.

Chadwick turned out to be less diffident than Maurice had assumed. Six weeks later, Maurice approached Chadwick again, this time to ask about a letter he was preparing for *Nature* (1934, 1) about a phenomenon called delayed neutrons. "Were you the one who suggested the photodisintegration of the diplon to me?," Chadwick asked. Maurice nodded. "Well, it works," Chadwick informed him, "for the first time last night. Would you like to work on it with me?" (1979, p. 87). Maurice leapt at the chance. "I realized by then that I enjoyed pursuing questions that could be answered by experiment."

Switching from theory to experiment was less of a transmutation than it would be today. The Cavendish workplace was informal, and nuclear physics was at such an early phase that the disciplinary lines were not as hard and fast as they soon became. "I remained interested in theoretical developments," Maurice said later, "especially those that can be considered a continuation of experiments by other means." He found he loved the work. Maurice also had considerable freedom and resources, because Chadwick was occupied supervising other students as assistant director of research. These resources, minimal by today's standards (the entire Cavendish Laboratory, for instance, had only two Geiger counters), seemed more than ample then.

Among the principal topics studied by experimental nuclear physicists were nuclear *reactions*, or how nuclei change; *isotopes*, or nuclei with the same number of protons but different numbers of neutrons; and *isomers*, or "excited states" of nuclei, in which the same composites occupy different, long-lived energy states, analogously to the behavior of electrons in an atom. At the Cavendish, Maurice conducted experimental work in all three areas. Experimental science is the art of getting information you have to tell you information you do not yet have. Maurice's particular genius was his ability to use knowledge of properties of nuclear reactions, and in particular of spin, to design experiments to obtain new information.

The neutron's mass was a pressing issue for several reasons, bearing as it did on whether or not it was a proton-electron composite or something else. Measuring the mass was difficult because the neutron was uncharged. The way to measure the mass of a charged ion or particle—developed into a fine art in mass spectroscopy—is to make a beam of them, put the beam in a magnetic field, and measure the curvature. This could not be done with neutrons. Photodisintegration was a new technique that might make possible a precise measurement of the neutron's mass. If an energetic enough gamma ray were to strike the deuteron and separate the proton and neutron, then Einstein's two formulas—$E=mc^2$ and his photoelectric effect equation— along with conservation of momentum could be used to get information about the neutron's mass.

After six weeks of work, using an ionization chamber filled with D_2 gas, Maurice and Chadwick had a preliminary answer (1934,2). After a second experiment, the neutron mass turned out to be about 1.0013 times that of the proton and larger than the sum of proton and electron masses. This result showed that the neutron was not a proton-electron compound, and established the neutron as only the fourth elementary particle—along with electron, proton, and photon—though it also introduced a mystery that is still without deep explanation: why the neutron is heavier than the proton.

The discovery implied that the neutron might decay. Making a rough calculation based on crude experiments, Maurice figured that the half-life of a free neutron (one not in an atom) should be about half an hour (it was soon measured to be about ten minutes). At the time, he found shocking the idea that an elementary particle might be unstable.

While writing the paper, Maurice pondered whether the inverse reaction occurred—whether neutron plus proton could produce deuteron plus gamma. Another student of Chadwick's had done experiments involving neutrons striking paraffin that seemed to do just that. Maurice used his results to calculate the expected rate of the reaction, and found that the cross-section for this inverse reaction—or how big the neutrons "seemed" to the protons—was bigger than it should have been by orders of magnitude. This was extremely interesting. In the inverse process, where you see gamma rays emerging, the reaction may well be strongly dependent on the energy with which the neutron collides with the proton; the neutrons were being slowed down by the paraffin and only then absorbed by the protons. This suggested to Maurice the surprising result that slow neutrons have a large cross-section, which would shed much light on the dynamics of the nucleus. "Let's not speculate," Chadwick said, refusing to incorporate the suggestion in the article.

Maurice and Chadwick then set about following up the photodisintegration measurement with more work, including measuring the full angular distribution—what would be expected if it were indeed an electric dipole transition. For this purpose they needed heavy water. Fortunately, by this time Rutherford had a supply; indeed, most of the world's supply. When Maurice asked if it were available, Rutherford pulled out a piece of paper, wrote, "Oliphant [Australian Mark Oliphant], hand over 25 cc tube of heavy water to Goldhaber for the time being," and signed it with what Maurice called "the royal 'R'." He and Chadwick wrote up all this work in 1935, when Chadwick was leaving to become a professor in Liverpool (1935,1). It was only with the second paper that something close to the modern value for the neutron-proton mass ratio was obtained. The first experiment had a large enough uncertainty that it could not confirm a mass difference larger than the electron mass.

The Cavendish researchers kept abreast of the nuclear research in other centers. One center was Berlin, which Maurice had left. Another was Paris, where at Joliot's laboratory Hans von Halban and Peter Preiswerk were churning out papers. Their activity was the occasion for an early, oft-repeated Maurice witticism concerning the activities of a certain "Halbwerk" and "Preisan." With the deft syllable switch the names now meant "work-half-done" and "advertise," and was so obviously intended as an endearment that it even charmed Preiswerk's wife. Another center of nuclear physics research was Enrico Fermi's laboratory in Rome. Maurice was able to read Fermi's first published letters in the Italian he knew from deciphering the secret speech of his parents. In one of these, in fall 1934, Fermi announced the discovery that slow neutrons can have a huge cross-section, or the proposal that Chadwick had talked Maurice out of publishing.

This discovery galvanized Maurice, who wondered if other nuclei could be similarly disintegrated. He calculated various possibilities. One prospect was ^{10}B, but an obstacle was that the Cavendish amplifier was extremely sensitive to noise. He asked Rutherford for permission to stay late—after 6 p.m., when there would be less background noise—and Rutherford agreed. Maurice recalled the date—December 10, 1934—when he observed the boron disintegration at a rate indicating that its nuclei had a huge susceptibility, or cross-section, for slow neutrons.

Maurice soon found several other nuclear reactions in which slow neutrons had a high crosssection. In the course of one experiment he became almost certainly the first person to miss discovering fission. Studying uranium, he and a coworker covered the uranium with aluminum foil to stop natural alpha particles and to help find the more powerful alphas that would indicate the disintegration he was looking for. The foil, of course, stopped the fission byproducts that might have led Maurice—and he was not the only one to have missed fission this way—to discover uranium fission years earlier than it was (1935,1).

Yet another topic Maurice investigated was isomers. An isomer is a nucleus that has been excited and lives a long enough time in its excited state to be measured. There was one isomer known in natural radioactivity, which Hahn and Meitner had discovered in 1921, ^{234m}Pa. Maurice, Szilard, and Hill found another in 1935 and thoroughly studied it. The experiment involved taking a stable nucleus, ^{115}In, knocking it into a higher state, ^{115m}In, where it lived for hours, and studying its decay. It was spin 9/2 in the ground state and spin 1/2 in the excited state, so the gamma ray had to be emitted with a big angular momentum. It was the first well-understood nuclear isomer, and a breakthrough in understanding isomers. But by the time the three of them published, in 1939, they were already in the United States.

Maurice also worked with another graduate student, H. J. Taylor, who had been trying to use nuclear emulsions at the Cavendish. Maurice introduced several improvements—for which he was later extremely proud— which made them effective. The plates were manufactured by the Ilford company, and the pair sent various elements to Ilford to be incorporated directly into the emulsions for this research (1935,2).

In 1936 Maurice received his Ph.D., as well as a fellowship enabling him to remain at Magdalene College for two years. He also reconnected with Gertrude Scharff. After her semester in Berlin in 1932, she began working in Munich under Walther Gerlach, doing research in what today would be called condensed matter physics, studying the effect of mechanical stress on magnetization at high temperatures. She was able to complete her Ph.D. in 1935 shortly after the people in her department realized she was Jewish. She left for London, and after many months with no job obtained a position at Imperial College with G. P. Thomson, whose interest still was in electron diffraction. Her father, a successful businessman, remained in Germany, reluctant to move despite the collapsing political situation. Two years after World War II began her parents and maternal grandmother were rounded up and put on a train carrying about a thousand people to be “resettled” in Latvia. As the family learned only after Trude’s death, all were taken off the train near Kaunus, Lithuania, and shot by a combination of local “volunteers” and *Schutzstaffel* (SS).

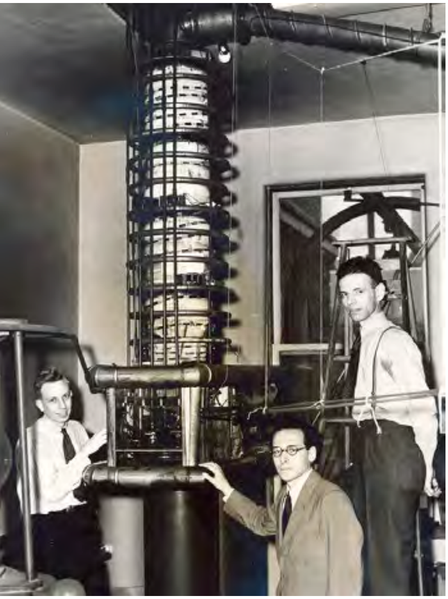
In 1937 Rutherford died. Lawrence Bragg succeeded him as head of the Cavendish. Maurice sensed, correctly, a looming sea change in the Cavendish research programs, and began to look around. In 1938 he visited the United States for the first time, to attend the April meeting of the American Physical Society in Washington, D.C. There he encountered Wheeler Loomis, chair of the physics department at the University of Illinois at Urbana, who offered Maurice a job. Jobs were scarce, and Maurice soon accepted. But immigrating to the United States was not easy with the flood of refugees then fleeing Germany. Maurice found immigration officials not helpful until they asked him if he taught—teachers received preferential treatment. “I’ve tutored,” Maurice said, remembering Ramsey. He got the visa.

Shortly after he arrived, at the end of 1938, a pair of German chemists discovered fission in uranium, and thus the possibility of an energy-producing chain reaction. This raised in turn the possibility of a new type of bomb, just as Europe was sliding toward another world war. “For nuclear physicists the age of innocence had ended” (1993, p. 24).

Group leader: Urbana (1938-1950)

Again Maurice was lucky; Urbana was a lively and productive place to be a physicist. Wheeler Loomis had managed to obtain funds to build up his department in the middle of the Depression. Jobs were scarce, and Loomis stocked his department with state-of-the-art instruments and excellent people. The instruments included a Cockroft-Walton accelerator for nuclear physics experiments, built by John Manley, and a cyclotron built by Ken Green and Jerry Kruger for particle physics experiments. Theorists besides Maurice included Robert Serber, an associate of J. Robert Oppenheimer. Two more Oppenheimer students would shortly arrive as well: Sid Dancoff in 1940 and Philip Morrison in 1941. Experimenters included Leland Haworth. Among other work at the University of Illinois, Maurice was involved with the first radiobiological studies using the neutron-^{10}B reaction.

In May 1939 Maurice (still known for a time as Moritz) traveled back to London to marry Gertrude, and the two returned to Urbana together. Because of an antinepotism policy they could not both hold positions at the university, and Gertrude could not get an official job. But Maurice assigned some of his students to her, and she took over his lectures when he was absent.



L. to R. John Manley, Maurice Goldhaber, and Leland Haworth with the Cockroft-Walton accelerator they built in Urbana.
(Department of Physics, University of Illinois at Urbana. Champaign, courtesy AIP Emilio Segre Visual Archives.)

On July 4, 1940, their first child was born: Alfred Scharff Goldhaber. The birth certificate is revealing. His father's name is given as "Moritz," his mother's as "Gertrud," leaving off the final *e* as per the German style. While his father's occupation is listed as "professor" at the "University of Illinois," his mother's occupation is given as "housekeeper" in "own home," which was surely humiliating. The family was still living in temporary quarters, and as a result the birth certificate listed his mother's mailing address as "Physics Department, University of Ill., Urbana." Their child was, it seems, born to be a physicist. That was not the only peculiar aspect of their child's birth. Until then, Urbana had an astonishing statistic, with something like 20 girls in a row born to professors in the physics department. The physicists proposed explanations to try to save this invariance. Loomis proposed that Alfred had been conceived before the Goldhabers arrived in Urbana, and so did not count, though this explanation seemed at variance with relevant travel documents. Maurice tried to save the invariance in another way, proposing the following rule: one physicist makes a girl, two physicists make a boy. This explanation seemed to be confirmed when the couple gave birth to another son, Michael Henry Goldhaber, on September 9, 1942. Both brothers were to obtain doctorates in theoretical physics, though Michael's interests later turned to socioeconomic criticism as well as creative work in art and writing.

Urbana was relatively isolated. But several young theorists distributed throughout nearby Midwest universities created a floating seminar that met once a month, variously in Urbana, Bloomington, Lafayette, St. Louis, South Bend, and Evanston. Maurice, who had learned to drive, joined them and enthusiastically offered the services of his car and driving ability, sometimes a little too enthusiastically, as Serber would later recall.

> *I went on a trip to Purdue as a passenger in Maurice Goldhaber's car. He had learned to drive only since arriving in Urbana, and his technique was to floor the accelerator and let her rip. On the way over, we descended an Indiana hill. We saw that it was crossed at the bottom by a railroad track occupied at the moment by a moving freight train. Maurice aimed to pass just behind the last car. Almost at the last moment we heard the whistle of another train, approaching the crossing in the opposite direction on a second track and hidden from us by the first train. On the way home, late that night, Maurice passed a car just before we reached the crest of a hill. When I remarked that this was dangerous he answered, "If a car were coming with the headlights on I'd see the scattered light."*[2]

The implications of fission took some months to dawn on nuclear physicists, as can be seen by a letter Maurice wrote in September 1940 to the general manager of a company that looked as if it might be able to provide him with heavy water, a letter whose tone is blissfully innocent of the horrific military possibilities. A mixture of uranium and heavy water, Maurice wrote, might be used "to sustain a nuclear chain reaction which would lead to large scale production of neutrons, radio active materials and energy."
If this possibility is confirmed, Maurice continued, "I can foresee a possible market for large quantities of heavy water, if its price can be reduced below one-tenth of the present rate."[3] However, Maurice was in contact with his friend Leo Szilard, who had been thinking about the possibility of nuclear weapons for years, and who ghostwrote Einstein's famous letter to Franklin D. Roosevelt advocating work on an American project to build one. Thus Maurice was fully aware of the bomb speculations, and the efforts to get the United States involved in their production.

Shortly after Pearl Harbor, some of the Urbana physicists, including Serber, began to disappear, conscripted into the Manhattan Project to build the first atomic bomb. Partly because Maurice and Gertrude were recently arrived foreigners with relatives still in Germany or German-occupied territory, they would not go, though the project surely would have benefited from their ongoing research into nuclear physics and nuclear cross-sections. During the war, they continued to work on nuclear research, some of which was declared secret, voluntarily withheld, and only published after the war.[4] Meanwhile, the pair also became naturalized citizens; on March 8, 1944, he was now formally Maurice Goldhaber.

Goldhaber with Wolfgang Pauli, autumn 1958. (Courtesy of Brookhaven National Laboratory.)

After the War, the Goldhabers continued work at Urbana. In an elegant tabletop experiment, using a radioactive source obtained from Oak Ridge, they demonstrated the identity of beta rays and atomic electrons (1948, 1). Everyone assumed these were the same, but the identity remained unproven. The Goldhabers used a trick based on the Pauli principle, according to which two identical particles cannot be in the same state. They took beta rays and shot them at lead. Slowing down, the particles should fall toward the nucleus, finally ending up in the K shell to produce an X ray. But they found few X rays, indicating that beta rays were not ending up in the K shell, for they were being blocked by the identical electrons already there.

Maurice worked one day a week at Argonne National Laboratory studying isomers at the CP-3 reactor built as part of the Manhattan Project. He was fascinated by isomers, for he suspected they were not distributed by chance but clustered in some regions and not in others. If he could find rules of their distribution, it might provide clues to nuclear structure. Reactors, which created beams of neutrons, now made creating, discovering, and studying isomers easier than ever before, and he studied their energies and spins. At the CP-3 his group included Ed der Mateosian from Argonne and Maurice's students Robert Hill (who had come from the Cavendish), Andrew Sunyar, John Mihelich, and Mike McKeown from Illinois. Der Mateosian recalled,

> *We studied seven-second activities, isomers that lost half their strength every seven seconds. When we did them that short, we'd first clear the halls and one of us would stand by the reactor, while another, wearing tennis shoes, stood outside the laboratory door. The guy by the reactor would grab the container right after the sample was irradiated and throw it down the corridor to the other guy in tennis shoes, who would rush it to the detector, and we'd start counting.*[5]

Other students of Maurice's at Illinois include Carl Muelhaus and Rosalyn Yalow. Walter Meyerhof was a postdoc who worked mostly with Trude. The work of Maurice and Trude helped shepherd in the emerging shell model of the nucleus being developed by Maria Mayer in Chicago and Hans Jensen in Heidelberg, and the shell model helped Maurice's isomer studies in turn. He also wrote an early paper with Edward Teller on an example of collective behavior in nuclei: vibration of neutrons against protons (1948, 2).

Meanwhile, a state-of-the-art research reactor with an improved neutron flux was being built at another one of the U.S. national laboratories, Brookhaven National Laboratory (BNL). Several Illinois physicists were recruited there, including Kenneth Green and Leland Haworth, while Norman Ramsey was the first head of the new lab's Physics Department. Ramsey was finding recruiting experimental physicists difficult, because the reactor was not completed yet. In 1947 he tried to entice Maurice and Gertrude, pointing out that the lab had no antinepotism provisions and both members of the couple could hold positions. Maurice was reluctant, given that the reactor's completion was still three years away. Still, they went for the summer of 1948, and discovered an isomer in tellurium in a sample shipped from Oak Ridge. Ramsey kept the job open. The Goldhabers returned in the summer of 1949, and worked at BNL through the fall, returning to Urbana early in 1950. Here's how Maurice described the reason for the move:

> *Then came one of those little incidents, which happen in life as well as physics, which finally push you clean over a threshold. Trude and I had talked about the Brookhaven offer during the drive back to Illinois, and still hadn't decided whether to take it. When we reached the Urbana campus, we parked in front of the physics department, as we often did, to put our books back in the office. It was a weekend afternoon, and we were inside all of five minutes. When we came out, there was a parking ticket on the car window. There had never been any restrictions against parking there before. That decided us: "We're leaving."*[6]

They arrived later in 1950. Trude became the first female Ph.D. on Brookhaven's scientific staff.

Group leader: Brookhaven National Laboratory (1950-1960)

Brookhaven National Laboratory (BNL) was an exciting place to move for a nuclear physicist in 1950.[7] That August it had just commissioned the Brookhaven Graphite Research Reactor, the world's first reactor designed from the outset for experimental research. Samples were inserted into the reactor by pneumatic devices, and then sent directly to nearby laboratories. Maurice could easily search for isomers, even extremely short-lived ones, by irradiating samples and putting them almost immediately next to scintillation counters. His group discovered new isomers and new kinds of transitions (1951, 1). The group also proposed new terminologies and classification schemes for isotopes (1952). It also examined electromagnetic transitions and composed an influential review article on the subject (1955).

Maurice Goldhaber in 1951.
(Courtesy Brookhaven National Laboratory)

Maurice was, as always, a steady source of ideas even in unusual circumstances. A graduate student, in an unusual breakdown of security at the Cosmotron (BNL's most powerful accelerator at the time), continued to work on an experiment directly in the beam's path, not realizing that the machine had been switched on. Health physicists realized that he had received a large dose of protons to the chest but did not know how much. Maurice figured out a way to compute it by measuring the calcium activity that the protons had made after striking the buttons of his shirt.

Shortly after arriving at BNL, Maurice and Trude held a party at their onsite apartment to introduce themselves to their new neighbors. As partygoers will, they eventually precipitated into clusters of like disciplines, and the Goldhabers soon found themselves sharing research ideas with a group of physicists. A doctor in a nearby cluster, eavesdropping, took Maurice aside and asked, “Aren’t physicists afraid others will steal your ideas?”

That was not the style of physicists and especially not Maurice’s. Maurice, in fact, became known for making insightful offhand remarks that set others on discovery paths. One example took place in February 1955, when Abraham Pais came to BNL to speak about an idea that he and Murray Gell-Mann had about the mixing of K particles.

> *Goldhaber, who was sitting in the audience, pointed out to the participants something that everybody implicitly knew but had not yet mentioned—that, just as the phase of light shifts when light passes through glass, the passage of K-particles through matter would shift their phase. The remark excited the audience members, including Oreste Piccioni and Pais, who missed the train he wanted to catch in the ensuing commotion. After all, passing the K-particles through matter could allow experimentalists to transform K-longs into K-shorts or vice versa.*[8]

Pais and Piccioni soon wrote an article on the idea, called K-particle “regeneration,” and the effect was soon discovered. Pais later said that of all his research work, he was proudest of this one.

By this time Maurice’s group had largely exhausted the task of identifying and classifying isomers, and the emergence of a comprehensive nuclear model by Aage Bohr and Ben Mottelson made the subject less scientifically interesting. Maurice’s interests began to shift toward particle physics, in which several fundamental issues were then being explored.

One was the stability of the proton. Maurice was the first to wonder whether the proton was stable, and wrote a paper on the subject with Reines and Cowan (1954).

> *It has often been surmised that there exists a conservation law of nucleons, i.e., that they neither decay spontaneously nor are destroyed or created singly in nuclear collisions. In view of the fundamental nature of such an assumption, it seemed of interest to investigate the extent to which the stability of nucleons could be experimentally demonstrated.*

The authors proposed a scaled-up experiment using the large scintillation detector that Reines and Cowan had built for their neutrino search.

Maurice was on the losing side of a famous bet of the period. At one BNL party he found himself betting $500 that the antiproton, then being hunted (and soon found) by a team of experimenters at Berkeley, did not exist. In later years when this bet was recalled in his presence, Maurice, always proud of this judgment, reminded people that this was prior to the proposal of an asymmetry in the creation of matter and antimatter, and that he had been impressed by the fact that the world seemed to be created only out of protons.[9]

Another fundamental issue he helped address was the structure of the weak interaction. This topic was in considerable upheaval after the experimental discovery, early in 1957, of parity nonconservation in beta decay and thus the weak interaction. The shocking announcement suddenly directed attention to the weak interaction, or more precisely, to whether "a" weak interaction existed. Particle physicists had discovered several kinds of interaction of about the same strength—but were they the same force or different forces? Certain pieces of experimental evidence suggested that these had different structures, and thus were different forces.

A key piece of evidence would turn on the helicity of neutrinos, or their spin relative to the direction of motion. If a particle spins clockwise while moving away from the observer, its spin is said to point in the direction of motion and have positive helicity; if counterclockwise, it has negative helicity. The parity violation experiment left open the possibility that beta-decay neutrinos could be right-handed, which in conjunction with other experiments implied that beta decay had different structures and was not one force.

In October 1957 Maurice, who was well known as the expert on spin, was asked to survey this problem at the upcoming December meeting of the American Physical Society, at Stanford University. He stayed home one Friday morning in mid-October to read the relevant reprints. "Before I finished the first paper I thought, 'There must be a better way to do this.' Twenty minutes later, I had thought of one."[10]

In those twenty minutes Maurice mentally reviewed his knowledge of nuclear transitions and came up with one: an isomer of europium, ^{152m}Eu, in which the momenta and angular momenta of every other particle in the decay but the neutrino could be established. ^{152m}Eu undergoes K-capture, in which it absorbs an electron and emits a neutrino, transforming itself for a short time into an excited state of samarium, ^{152}Sm. ^{152}Sm emits a gamma ray to go to the ground state. If one could measure the momentum and spin of that gamma ray, one could figure out the momentum and spin of the neutrino that the ^{152m}Eu atom had emitted while turning into ^{152}Sm. These two pieces of information would then indicate the helicity of the neutrino. It looked like one could, thanks to the recent discovery of "resonance fluorescence" by BNL postdoc Lee Grodzins, the phenomenon that gamma rays emitted by excited ^{152}Sm would scatter strongly on unexcited Sm nuclei. Resonance fluorescence meant that when the gamma ray and the preceding neutrino came out in opposite directions, the Sm nucleus was left nearly at rest, which implied that the gamma ray had the right energy to excite another Sm, and make a wide-angle scatter. The photon had to go around a block in front of the source, scatter first on magnetized iron (a process sensitive to the helicity of the gamma, and then scatter on a ring of Sm and get bounced into the detector, which was shielded by the block from direct exposure to the source.

"On Monday morning, I rushed to the lab and said, 'Boys, drop everything!' And they did."[11] The "boys" were Grodzins and Andy Sunyar, and they carried out the experiment in Building 119 at Brookhaven. The experiment took about 10 days to complete, followed by a month of checks and rechecks. A paper was submitted to *Physical Review* on December 11, 1957; it was preceded by a paper by Grodzins alone on resonance fluorescence. Nine days later, on Friday, December 20, 1957, Maurice stood in front of an attentive audience at Stanford and told them the answer: the neutrino is left-handed, meaning that the weak interaction was probably one force after all.

It was a remarkable feat of experimentation. Of the thousands of known nuclear transitions, the one involving ^{152m}Eu was, and still is, the only one known to work. Most physicists at the time did not realize that it was even possible to measure the helicity of the neutrino. While many discoveries, including the disintegration of the deuteron, surely would have been made had their discoverers done something else, this one was different. Asked how he came up with the idea, Maurice liked to remark, "You work for twenty years on isomers, and think for twenty minutes."[12]

In the aftermath of that and other experiments over the next few months, the weak force was firmly established as a single fundamental interaction, opening the door for further exploration. For decades thereafter, moderators often introduced Goldhaber at conferences by saying, "Goldhaber's the one who" [and] then gesturing as if twisting a doorknob to open a door, instinctively rotating their hands clockwise in the process. The ever precise Goldhaber then would begin his talk by gently reminding the speaker that the neutrino is *left*handed, and repeat the gesture the other way.[13]

The outcome of that experiment was so decisive and important, providing a key component to the emerging picture of the weak interaction, that in 1958 he was elected to the National Academy of Sciences. A year later Maurice received his first nomination for the Nobel Prize.[14] Though he would never receive that honor, during his career he received much other recognition, including the Tom W. Bonner Prize in Nuclear Physics in 1971, the J. Robert Oppenheimer Memorial Prize in 1982, the National Medal of Science in 1983, the Wolf Prize in Physics in 1991, and the Enrico Fermi Award in 1999. He served as president of the American Physical Society in 1982. A physics graduate student prize in the name of Gertrude and Maurice Goldhaber has been offered for more than a decade at Harvard University, and Brookhaven National Laboratory offers postdoctoral fellowships in that name. In 2009 Magdalene College, Cambridge University, established the Maurice Goldhaber Prize for Natural Sciences or Mathematics, in honor of alumnus Maurice Goldhaber, and in 2011 the University of Illinois Physics Department established a graduate student prize in his name.

Goldhaber in 1959. (Courtesy of Brookhaven National Laboratory.)

Maurice also published several notable speculative articles: that there might be an anti-universe to account for the nonexistence of antimatter in our own universe (1956); that fermions might be doubled (1958, 2); and that strange particles might be composites of K-particles and nucleons (1953). Subsequent theorists of the multiverse, and of the three generations of particles such as leptons and quarks, as well as the quark modelers themselves, later cited these works as antecedent to their own.[15] In 2005, for instance, at a Stony Brook conference on general relativity titled “Geometry and the Universe,” a visiting speaker pointed out to Maurice that his early suggestion of an initial state of a single particle decaying to two, the “cosmon” and the “anti-cosmon,” with the former being the progenitor of our universe, could be seen as the origin of the kind of thinking discussed in recent speculation about a multitude of universes.

Lab director: Brookhaven National Laboratory (1961-1972)

In 1960 Maurice became chair of Brookhaven's physics department. A year later after the lab's longtime director Leland Haworth became a commissioner of the Atomic Energy Commission, Maurice was selected as director of the entire laboratory.

> *Goldhaber was still a dashing-looking fifty despite a set of heavy, horn-rimmed glasses that obscured his clear features. He spoke carefully, in a voice with a musical lilt and the soft timbre of a tenor clarinet, and in phrases that gave off the impression of an experienced, if somewhat detached, intelligence. An occasional twinkle in the eye and slight upturn at the corners of his mouth were the only physical manifestations of an impish streak that often manifested itself in witty pronouncements.*[16]

Maurice brought a much different style to the lab directorship than did Haworth. Haworth, of Quaker upbringing, was conservative and plain—under him the director's office had concrete block walls and no rug on the floor—and something of a micro-manager. Maurice brought more of a sense of elegance and gravitas to the directorship. He had the director's office enlarged and renovated, and many lab buildings renovated as well. He also delegated, and appointed associate directors to handle issues that Haworth would have assigned to himself.

By the time Maurice stepped down as BNL director, in 1972, research had been conducted at the lab that eventually would reward three discoveries with Nobel Prizes: the discovery of the muon neutrino in 1962 (awarded 1988), the discovery of CP violation in 1963 (awarded 1980), and the detection of solar neutrinos in the late 1960s and early 1970s (awarded 2002).

The gentlemanly class that Goldhaber brought to the lab extended even to its series of elegant Christmas cards. Goldhaber would choose a cover depicting an important discovery or development, emblematic of the lab, that had taken place there that year. These cards reveal where his heart lay: in the scientific accomplishments of the institution.[17]

A message that ruffled some feathers, but still resonates today, was "Speak of experiments in the past tense, theories in the present tense, and accelerators in the future tense." One very useful motto of his that did not appear on a card was, "Never pooh-pooh a factor of two!"

Alfred Scharff Goldhaber, Michael Goldhaber, David Goldhaber-Gordon, Gerson Goldhaber, and Maurice Goldhaber at "Gersonfest" celebrating Gerson Goldhaber's 50 years at Lawrence Berkeley National Laboratory and at the University of California at Berkekley. (Courtesy of Lawrence Berkeley National Laboratory)

Under Maurice the accomplishments were superb indeed. Brookhaven's Alternating Gradient Synchrotron had just come on-line, the forefront particle accelerator in the world for many years. By the time Maurice stepped down as BNL director, in 1972, research had been conducted at the lab that eventually would reward three discoveries with Nobel Prizes: the discovery of the muon neutrino in 1962 (awarded 1988), the discovery of CP violation in 1963 (awarded 1980), and the detection of solar neutrinos in the late 1960s and early 1970s (awarded 2002).

Especially the last experiment illustrated Maurice's principle that disciplinary and other boundaries should not stand in the way of "scientific hot pursuit." Ray Davis, a radiochemist, wanted to seek neutrinos from the sun. Not only was this an example of astronomy and elementary-particle physics, it also required use of a deep mine in North Dakota. Nevertheless, once Maurice was satisfied that the experiment was feasible, he gave it his full backing.

While director, Maurice continued to maintain a lively interest in research, thinking carefully about experimental proposals at BNL, and giving valuable advice to experimenters. He also cooperated with colleagues on experiments, for example, searches for double beta decay, as well as with theorists on a variety of topics ranging from conservation laws to properties of atoms containing omega-minus particles. He obtained a patent for a combined hydrogen-neon bubble chamber, in which by varying the ratio of the two elements one could vary the production of photons and electron pairs by charged particles participating in observed reactions.

Proton decay: Brookhaven National Laboratory (1973-1985)

After stepping down from the lab directorship, Maurice continued to engage in research, and took a lively interest in the IMB experiment to attempt to detect proton decay, whose principals were from the University of California at Irvine, the University of Michigan in Ann Arbor, and BNL. Maurice initially was the only member at BNL—“I’m the ‘B’ in IMB,” he liked to say. The IMB collaboration lasted from 1983 to 1997, during which time it built and operated an experiment in a salt mine in Ohio, which failed to detect proton decay in the domain of its sensitivity. In 1998 it was folded into a larger experiment in a mine in Kamioka, Japan, the Superkamiokande Nucleon Decay Experiment, which had been in service since 1983, and also has yet to find evidence for proton decay.[18] Maurice, who was then in his mid-80s, showed up for Super-K collaboration meetings, and even several in Kamioka itself. His impact was mostly inspirational, recounting for colleagues young and old the history of the efforts that led to the collaboration and dispensing occasional ideas and frequent witticisms. In response to talk about “candidate” events for proton decay Maurice liked to say, “Not all candidates are elected.” In response to proposals that the evidence they were finding might support “supersymmetric” theories, the names of whose predicted particles often were prefixed with an “s,” Maurice would say, “Only sgod knows.”

Retirement (1986-2011)

After his retirement, Maurice continued to come to Brookhaven every day, even after Gertrude died in 1998. At first he drove himself; later, in his 90s, a colleague or a driver would take him to and from the lab. Physicists in Building 510 at Brookhaven—the Physics Building—knew that he could always be found in his office, available for consultation. He continued to work on papers though his publication rate declined. One paper, for instance, with Baltz and Alfred Goldhaber, argued that not only is the mixing between mu and tau neutrinos large, as had been determined, but so is the mixing between electron neutrinos and neutrinos of other flavors (1998).

Alfred and Trude Goldhaber, autumn 1970. (Courtesy of AIP Emilio Segre Archives, Physics Today Collection.)

In 2008 the laboratory celebrated the 50th anniversary of the neutrino helicity discovery with a conference. Though 97 years old, Maurice still insisted on walking to the podium and presenting his views on the future of physics. He continued to be a witty presence with a seductive charm. Shortly after entering one lab party, he noticed an elegant woman chatting with the BNL historian and was determined to enter the conversation. “Don’t you know he’s a historian?” Maurice said in interposing himself. “You are much too young to be of interest to him!”

In August 2009 Maurice became too frail to travel, and moved to a retirement community in Setauket, near his son, Alfred, a physics professor at the nearby Stony Brook University. While visits to the lab ceased, the occasional visitor who wanted to consult him continued to do so. His work, though slower, also continued. One of his ongoing interests was neutrino mass. Together with Alfred, he set out to demonstrate the impracticality of noticing reversed neutrino helicity. The paper was published in *Physics Today* in May 2011, the same month that this phenomenally inventive and productive man passed away after a short illness.

It was a typical Maurice paper, which put together existing information to reach a counterintuitive conclusion—one different from that implied by casual reflection. Not for Maurice to speculate wildly based on yet undeveloped technology. As he liked to remark, “A genius knows what to leave to the next generation.”

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NOTES

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3. M. Goldhaber to E. F. Goodner, September 20, 1940.
4. For example, J. W. Coltman and M. Goldhaber. "Capture cross sections for slow neutrons," received by *Physical Review* on June 12, 1941, but voluntarily withheld from publication until the end of the war.
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6. Ibid., p. 168.
7. Crease, *Making Physics*, op. cit., Chapter 8.
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10. Crease, *Making Physics*, op. cit., p. 248.
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14. R. A. Marshak to the Nobel Committee for Physics, January 20, 1959, courtesy of the Royal Swedish Academy of Sciences, Center for History of Science, Stockholm.
15. M. Gell-Mann and Y. Ne'eman, *The Eightfold Way*; p 302. New York: W. A. Benjamin, 1964.
16. Crease, *Making Physics*, op. cit. p. 261.
17. Ibid., p. 262.

18. Two key IMB papers are:

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