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EUGENE PAUL WIGNER

1902—1995

A Biographical Memoir by

FREDERICK SEITZ, ERICH VOGT, AND
ALVIN M. WEINBERG

Biographical Memoir

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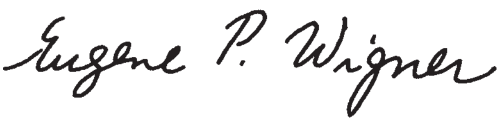

EUGENE PAUL WIGNER

November 17, 1902–January 1, 1995

BY FREDERICK SEITZ, ERICH VOGT,
AND ALVIN M. WEINBERG

EUGENE WIGNER WAS A towering leader of modern physics for more than half of the twentieth century. While his greatest renown was associated with the introduction of symmetry theory to quantum physics and chemistry, for which he was awarded the Nobel Prize in physics for 1963, his scientific work encompassed an astonishing breadth of science, perhaps unparalleled during his time.

In preparing this memoir, we have the impression we are attempting to record the monumental achievements of half a dozen scientists. There is the Wigner who demonstrated that symmetry principles are of great importance in quantum mechanics; who pioneered the application of quantum mechanics in the fields of chemical kinetics and the theory of solids; who was the first nuclear engineer; who formulated many of the most basic ideas in nuclear physics and nuclear chemistry; who was the prophet of quantum chaos; who served as a mathematician and philosopher of science; and the Wigner who was the supervisor and mentor of more than forty Ph.D. students in theoretical physics during his career of over four decades at Princeton University.

The legacy of these contributions exists in two forms. First, there are the papers–in excess of five hundred–now included in eight volumes of his collected works.[1] His legacy also resides in the many concepts and phenomena that bear his name. There is, for example, the Wigner-Eckart theorem for the addition of angular momenta, the Wigner effect in nuclear reactors, the Wigner correlation energy, as well as the Wigner crystal in solids, the Wigner force, the Breit-Wigner formula in nuclear physics, and the Wigner distribution in the quantum theory of chaos.

His collection of essays *Symmetries and Reflections*[2] provides an insightful view of the many intellectual matters that concerned him during a busy career. The recollections of his life[3] recorded by Andrew Szanton when Wigner was in his eighties provide a special insight into the circumstances of his life and the incidents that brought him to the fore.

EARLY HISTORY

Wigner was born in Budapest on November 17, 1902, into an upper middle class, predominantly Jewish family. His father was manager of a leather factory, and clearly hoped that his son eventually would follow him in that post. He had two sisters. The family roots lay in both Austria and Hungary. The two major events that disturbed the tranquil course of his formative years were World War I and the communist regime of Bela Kun, which followed it. Since his father was of the managerial class, the family fled Hungary to Austria during the communist period and returned a number of months later, after the regime of Bela Kun had been deposed.

For his secondary school education, Wigner attended the Lutheran *gimnazium,* which had a dedicated and highly professional teaching staff. Wigner regarded himself an excellent student, but not an outstandingly brilliant one. Throughout his lifetime, he mentioned his debt to two individuals he met through that school. First was his mathematics teacher, Laslo Ratz, who recognized that the young Wigner had exceptional if not rare abilities in mathematics. The second was a somewhat younger student, John von Neumann, who came from a wealthy banking family and who indeed was recognized by Ratz to be a mathematical genius and to whom he provided private coaching. Wigner formed a close friendship with von Neumann that was to endure throughout their lifetimes. As students, they would often walk home together while von Neumann related to Wigner the wonders of advanced mathematics, which the former was absorbing.

TECHNISCHE HOCHSCHULE, BERLIN

While Wigner was strongly attracted to the field of physics, his father, who was of a very practical mind, insisted that instead he attend the Technische Hochschule in Berlin and focus on chemical engineering, so that he might be in a better position to earn a living in Hungary. Wigner followed his father's advice and in 1920 found himself in Berlin. There he spent a substantial part of the day mastering several fields of chemistry, as well as the arts and practice of chemical engineering, which he retained in full force for important use during World War II.

His heart, however, was still devoted to physics, which was in a state of major transition. He spent essentially all of his spare time at the University of Berlin attending seminars and colloquia, where he frequently found himself listening intently to discussions in the presence of the great figures of the time. His interest deepened. It should be added that von Neumann's parents had also insisted that von Neumann focus on chemical engineering, so that he would have a reliable practical background, although his major interest continued to be mathematics.

There was a small but prominent Hungarian community in academic circles in Berlin. Wigner soon formed relationships with its members, which remained close throughout their lifetimes. One of the special links was with Professor Michael Polanyi, a generation older, who gave very generously of his time and attention. He also met Leo Szilard, whom he often referred to as "the general," since Szilard enjoyed making decisions. Other Hungarians Wigner met through the Berlin connections were Dennis Gabor and Egon Orowan. He also renewed there a friendship with Edward Teller, whom he had known as a younger student in Budapest, and who was then working with Heisenberg in Leipzig.

RETURN TO BUDAPEST

Wigner returned to Budapest in 1925 to take a position in his father's leather factory. It was then that he learned of Heisenberg's highly innovative development of the matrix version of quantum mechanics. While he was not entirely happy with his work and circumstances in Budapest, he would have carried through indefinitely in order to be supportive of his family and its wishes.

RETURN TO BERLIN

A year or so after becoming re-established in Budapest, Wigner received an offer of a research assistantship in Berlin from Professor Karl Weissenberg, an X-ray crystallographer at the University of Berlin. When he discussed the matter with his father, the latter was not entirely pleased, although he recognized the intensity of his son's desire to become a professional scientist. Finally, his father decided to let his son return to Berlin, where the latter learned that Michael Polanyi had been instrumental in having the offer extended.

Since Wigner had a very fine command of mathematics, Weissenberg frequently posed problems of a semi-complex nature that had mathematical roots. This led the young novice to explore elementary aspects of symmetry or group theory as he struggled to try to satisfy Weissenberg's curiosity, as well as his own. In the meantime, Heisenbergs's matrix version of quantum mechanics was followed by Schroedinger's wave-like formulation.

Once caught up in symmetry theory, Wigner wondered if it had applications in the field of quantum mechanics. This led him to discuss the issue with von Neumann, who, after pondering the problem briefly, recommended that he read the papers of G. Frobenius and I. Schur on the irreducible representations of symmetry groups. Wigner soon became immersed in the field. He realized it opened a vast new area of mathematical physics for exploitation, the initial applications being to the degenerate states of symmetrical atomic and molecular systems. What many physicists came to call the "group theory disease" was born, with very far-reaching effects.

This initial work of Wigner on group theory and quantum mechanics[4,5] had a profound impact on all of fundamental physics and on Wigner's own subsequent development as a scientist. He understood that the superposition principle of quantum mechanics permitted more far-reaching conclusions concerning invariant quantities than was the case in classical mechanics. With the tools of group theory, Wigner derived many rules concerning atomic spectra that follow from the existence of rotational symmetry.

After a number of months, Weissenberg arranged for Wigner to become a research assistant to Professor Richard Becker, who had been newly appointed to a chair in theoretical physics at the university. Becker was very generous in allowing him to follow his own leads for self-development.

SHIFT TO GÖTTINGEN

In 1927 Richard Becker proposed that Wigner spend a period in Göttingen as an assistant to the very distinguished mathematician David Hilbert. Göttingen was at that time one of the greatest world centers of mathematics, with a continuous history in that field going back to the time of Karl Gauss. Moreover, it was very strong in theoretical physics. Unfortunately, Hilbert had become seriously ill and withdrew essentially permanently from professional work, so that Wigner found himself with a position with no formal responsibilities. He did form, however, friendly links with individuals such as James Franck. He also undertook a cooperative research program with Victor F. Weisskopf, then a student, with whom he published a paper on spectral line shape.

WIGNER'S SOLILOQUY

Having much time to himself in Göttingen because of the special circumstances he encountered there, Wigner decided to come to terms with himself and his new career. After much pondering, he came to three broad conclusions. First, he would devote his life to the further advancement of physics. Second, whenever possible, he would do his best to apply his knowledge of physics to the well being of mankind. Finally, having discovered that the field of group representations opened entirely new vistas in the applications of quantum mechanics, he would follow that area of development as the main lead in his future work.

Just at this point, Leo Szilard earnestly requested that Wigner write a book on group theory and its applications that would be understandable to physicists, particularly members of the younger generation. Soon after Wigner published his first work in the field, the mathematician Hermann Weyl, became interested in the topic and wrote a book on the subject, which was rather inaccessible for most physicists. Thus, Wigner began writing his famous book *Group Theory and Its Application to the Quantum Mechanics of Atomic Spectra*,[6] a continuing classic. In a sense, Wigner reclaimed his birthright while rendering a service.

RETURN TO BERLIN

In 1928 Wigner returned to Berlin and continued his work there. Among his many contributions to the field of quantum mechanics during this period was a paper devoted to the theory of chemical reaction rates that he developed in cooperation with Michael Polanyi and Henry Eyring, a visitor from the United States. The approach used was generalized later by Eyring and applied to many chemical problems. Wigner and Eyring were to become colleagues once again during the 1930s while both were on the Princeton faculty.

PRINCETON BECKONS

In the autumn of 1928 Wigner, again out of the blue, received a most remarkable letter from Princeton University asking if he would be willing to serve for one year as a half-time lecturer in mathematical physics at what for him was an enormous salary. The offer undoubtedly had a complex origin. Oswald Veblen, a distinguished, worldly professor of mathematics at Princeton who hoped to make Princeton the American equivalent of Göttingen in mathematics and mathematical physics, decided that a great advance would be achieved if John von Neumann would join the Princeton faculty on a full-time basis. This idea was by no means far-fetched because von Neumann had decided as early as the mid-1920s that it was very likely that Europe would experience another great war that would be accompanied by a vicious wave of anti-Semitism. He concluded at that time that he would eventually explore possible openings in the United States. When Princeton tried to acquire him on a full-time tenured basis in 1928, he decided he was not yet ready to go that far in terminating his European links and suggested that he and Wigner share the appointment on a half-time basis. Princeton agreed, with the understanding that Wigner's appointment would not carry tenure. In any event, both Wigner and von Neumann found themselves settling in at Princeton on a part-time basis in 1930.

Von Neumann enjoyed his life in the United States immensely from the very beginning. He formed friendships easily, and was soon leading a very stimulating life with his vivacious Hungarian wife, who had joined him. For Wigner, in contrast, the transition was a relatively difficult one. He not only found the informalities of American life strange relative to those in Europe, which suited him so well, but had special difficulty adjusting to Princeton, which had its own somewhat closed social structure. He lived a fairly lonely existence, except for the professional links that grew out of mutual research interests with some members of the faculty.

Not least, Wigner brought with him to the United States the standards of polite social behavior that had developed among the members of the upper middle and professional classes in Europe. There is an almost endless lore of "Wignerisms" that have circulated within the community associated with him. It was essentially impossible not to obey his insistence that you pass through a door before him. Individuals, on wagers, invented ingenious devices, which usually failed, in attempts to reverse the procedure. On one occasion, he encountered an unscrupulous merchant who attempted to cheat him in a too obvious way. Wigner, angry and now somewhat seasoned in vernacular terminology, terminated the negotiation abruptly by saying, "Go to Hell, please!" He often received requests from other individuals to read a research paper written by the latter. If he found many errors, he was very likely to return it with the ambiguous comment, "Your paper contains some very interesting conclusions!"

During that first year, both the mathematics and the physics departments were sufficiently pleased with the arrangement involving von Neumann and Wigner that it was extended on the half-time basis for a five-year period.

As Wigner was preparing to return to Berlin at the end of January 1933, it was announced that President Hindenburg had appointed Adolph Hitler chancellor. Wigner was dismayed, since he knew that his appointments in Berlin would be canceled because of his Jewish background. He returned to Budapest instead of Berlin. During the following year, he decided it would be wise for him to become a U.S. citizen, and citizenship was granted in 1937.

PREWAR YEARS OF RESEARCH

Along with the many other investigations related to physics and chemistry, Wigner initiated advances in three major fields of physics in the prewar years, first at Princeton (1930-36), then during his two years at Wisconsin (1936-38), and after his return to Princeton. He helped open important parts of solid-state physics to applications of quantum mechanics. He was a true pioneer in unraveling the mysteries of nuclear physics, and he derived for practical use the irreducible unitary matrix representations of the continuous group associated with the Lorentz transformation. In each of these three cases, his work opened doorways to areas that were to expand continuously during the next half century as a result of his initial work.

In the field of solid-state physics, he and Seitz, his first graduate student, succeeded in developing an acceptable wave function for the ground state of metallic sodium.[7] When the results associated with it were joined with calculations of the exchange and correlation energies of a gas of free electrons carried out by Wigner, the so-called binding energy or energy of sublimation of the metal could be derived essentially from fundamentals using quantum mechanics. The field was opened further by Wigner in cooperation with several of his students, most notably John Bardeen, who later gained much fame for his primary contributions to the invention of the transistor and the explanation of low-temperature superconductivity. Among other individuals who worked with him in this area at that time was Conyers Herring, who subsequently served as a leading generalist in the field for half a century.

Immediately after the discovery of the neutron in 1932, Wigner studied the early measurements of neutron-proton scattering, the properties of the deuteron, the connection between the saturation property of nuclear binding energies and the short range nature of the inter-nucleon force, and the symmetry properties of the force.

Later in the 1930s, when beta-decay data and energy levels of light nuclei began to emerge, Wigner, together with Gregory Breit, Eugene Feenberg, and others, developed the supermultiplet theory[8] in which spatial symmetry played a key role in the description of nuclear states.

Soon after Fermi found the strong and sharp resonances in the bombardment of nuclei by neutrons, Breit and Wigner developed the very useful Breit-Wigner formula to describe the cross sections in terms of nuclear parameters. Underlying the formula was the concept of a short-lived transition state, somewhat analogous to Bohr's "compound nucleus" and to the transition state appearing in Wigner's conception of a chemical reaction.

In an epochal paper[9] published in 1939, Wigner turned his attention to the inhomogeneous Lorentz group. This group involves time-dependent symmetries, or symmetry groups that include time-translation invariance. The topic had not previously received serious study by mathematicians or physicists. He provided a complete answer to the two major questions he posed: (1) what are the unitary representations of the inhomogeneous Lorentz group and (2) what is their physical significance? In this case, an analysis of its irreducible representations provided a complete classification of all the then known elementary particles. This paper furnished a platform for the further development of relativistic quantum mechanics by Wigner and others in the post-World War II period.

In 1940 Wigner developed the algebra of angular momentum recoupling, using group theoretical methods prior to Racah's algebraic analysis in 1942. The paper,[10] far ahead of its time, had the rather esoteric title of "On the Matrices Which Reduce the Kronecker Products of Simply Reducible Groups." Wigner's friends advised him that the work was too esoteric to merit publication; it did not emerge in published form until twenty-five years later.

Incidentally, Dirac became a frequent visitor to Princeton starting in the early 1930s. Wigner had first met him at Göttingen and developed a strong liking for the very reserved Englishman. The two somewhat lonesome bachelors became close friends, each respecting the other's qualities. Dirac eventually came to meet Wigner's younger sister as a result of this friendship. They were married in 1937.

UNIVERSITY OF WISCONSIN, 1936-38

Although Wigner's non-tenured appointment at Princeton was extended beyond the initial five years, and he was promoted from visiting lecturer to visiting professor, it was not the tenured position he was looking for. He decided he was being rejected. As a result he found it necessary to search for another position during a period in the Great Depression when there were very few tenured vacancies. Fortunately, he succeeded in obtaining such an appointment at the University of Wisconsin with the help of a colleague there, Gregory Breit, who fully appreciated his merits. The warmth of the reception he received at the university made him feel at home very rapidly and he was soon productively at work again. In close cooperation with Breit, he continued to focus attention on nuclear physics. Among other things, they proposed a transition-state picture of nuclear reactions and the previously mentioned Breit-Wigner formula for the scattering and absorption of particles such as neutrons and gamma rays by nuclei. In later years, Wigner strengthened the mathematical foundations on which the relationship was based, using what has come to be termed R-matrix theory.

He also found himself greatly attracted to Amelia Frank, one of the young women members of the faculty. The two were married in December 1936. Unfortunately, she soon developed incurable cancer and died just a few months after their marriage, casting him into a deep depression.

In the meantime, Princeton had come to regret its decision regarding the "dismissal" of Wigner. As a result, he was invited to return to a tenured professorship in 1938. He might have refused under other circumstances, since by this time he felt more than a sense of gratitude to his many friends at the University of Wisconsin. Under the circumstances, however, he decided that it was very important for his own mental health that he leave the surroundings associated with so much grief, and he accepted the appointment.

NUCLEAR FISSION

The return to Princeton brought with it two major developments that rapidly drew Wigner into applied research, this time with feverish energy. It was obvious to him and von Neumann, as a result of the so-called Munich Peace Pact in the autumn of 1938, that the Second World War they had long anticipated was now near at hand and that England, France, and the United States were ill prepared to face it. To protect his parents from the rising power of Hitler, he convinced them to come to the United States, a necessary move to which they never succeeded in adjusting.

A few months later came the announcement of the discovery of nuclear fission by Hahn and Strassmann in Berlin, along with evidence for the large amount of energy released in the process.

In the meantime, Enrico Fermi, who had carried out much of the pioneering work on neutron-induced reactions, had taken the opportunity provided by a Nobel award to leave Italy and accept an appointment at Columbia University in New York City. Moreover, Leo Szilard, who had moved from Berlin to England when Hitler took power, decided to join Fermi in New York, since he also feared that war was imminent.

Leo Szilard, convinced since the 1920s that it would not be long before one would learn to extract an enormous amount of energy from the atomic nucleus, came dramatically alive with the discovery of fission and soon had both Fermi and Wigner deeply immersed in the problem of determining whether a fission-induced chain reaction was possible. By the end of the winter of 1938-39, they decided that the probability of success was high, provided they could obtain the necessary material support. One of the consequences of their conviction was the framing of the letter that Einstein, Szilard, and Wigner sent to President Roosevelt in July 1939 describing the potentialities of a nuclear bomb and warning that, since fission had been discovered in Germany, it was most likely that the Germans would be the first to develop it. It took two and a half years, the start of World War II, and the bombing of Pearl Harbor for the national leadership finally to respond to the need to make adequate resources available.

In the interim, Fermi and a small group working with him at Columbia, along with the cooperation of Szilard and Wigner, succeeded in measuring the various significant parameters, such as the number of neutrons produced per fission, that would determine whether a chain reaction was possible.

In June 1941 Wigner married fellow physicist Mary Wheeler, whom he had met through professional meetings. The two were soon living as happy a domestic life as one could hope for under wartime conditions and were raising two bright, talented children. This union finally freed Wigner from the long periods of loneliness he had experienced since first coming to the United States. The next four decades were happy ones until Mary died of cancer in 1977. Two years later he married Eileen Hamilton, the recently widowed wife of the dean of graduate studies. The two shared close companionship until Wigner's death.

UNIVERSITY OF CHICAGO

By September 1941 there was no doubt about the feasibility in principle of developing a nuclear chain reaction. Moreover, the government decided to concentrate the initial effort of achieving that end at the University of Chicago under the leadership of Arthur H. Compton. Fermi was made director of the experimental research program and Wigner was placed in charge of a theoretical group that would follow developments and explore future possibilities. A strong chemistry group, which could achieve practical means of separating fissionable plutonium from the other by-products of nuclear fission, was also assembled. James Franck was placed in charge of that group, but a team led by Glenn Seaborg was given principal responsibility for carrying through the practical phases of the chemical work. The race was on!

The following few years gave Wigner an opportunity to put to use all of his experience and professional background, not least his careful training as a chemical engineer. While Fermi and his group moved ahead procuring materials of adequate purity and form for the construction of a graphite-moderated natural uranium reactor, Wigner formed a small staff, which, in addition to providing auxiliary help to Fermi, began to design large reactors that could produce practical quantities of plutonium. In his search among individuals not previously known to him, he found two scientists who became main players in his team. The two were Alvin M. Weinberg, a theoretical physicist who had just obtained his Ph.D. at the University of Chicago, and Gale Young, a practical mathematician who had been teaching at Olivet College.

Another major addition to the group was Edward Creutz who had previously joined the junior faculty at Princeton as an experimental nuclear physicist. Creutz realized soon after becoming part of Wigner's team in Chicago that the greatest service he could render was not as a nuclear physicist, but as a highly imaginative and flexible technical innovator. For he solved with speed and ingenuity many urgent problems related to metallurgy and radiation-induced effects that were barriers to progress and were beyond the range of traditionally experienced engineers.

Working with these partners and a small auxiliary staff, Wigner focused his attention on the design of large water-cooled, graphite, natural uranium reactors that would operate in the range of 500 megawatts, producing at optimum about 500 grams of plutonium per day.

By the time Fermi's reactor actually went critical on December 3, 1942, Wigner and his team had completed a task of almost unbelievable proportions, perhaps without equal in the annals of science and engineering. They had emerged with the effectively complete design of the full-scale Hanford production reactors. When the work began, a general outline was agreed on. The basic structure would consist of a lattice of natural uranium rods imbedded in channels extending through a graphite moderator. Some of the major design elements that needed to be determined as the group proceeded were the choice of coolant, dimensions of the lattice and reactor, and disposition of the control rods and cladding and tube materials. They also had to design the uranium fuel rods, determining whether they were to be hollow rods cooled internally or solid slugs cooled externally, all of which was accompanied by detailed analyses of matters such as pressure drops and heat transfer. Beyond this were issues related to the design of the outer shield and the method for loading and unloading. Wigner's personal imprint was on every aspect of the design. When the Dupont company later built the Hanford reactors, Wigner personally reviewed every blueprint.

The path Wigner and his team had to tread to reach their goal was not an easy one. Engineers brought into the program to provide independent advice offered alternative proposals for reactor design. In particular, there was strong support for a reactor that would be cooled by gaseous helium. It was necessary to demonstrate that such alternatives were substantially less desirable than a water-cooled system. Moreover, General Leslie Groves, who was in charge of the overall program, decided that responsibility for the final design and construction of the large plutonium-producing reactors should be given to the Dupont company and not to the staff of the Chicago laboratory.

Wigner felt this decision was wrong on two scores. Many valuable months would be lost while the inexperienced Dupont group became intimately familiar with the science and technology involved; his own team would inevitably be required to serve as frontline advisors, but would be in a completely subservient position. To appreciate the problems he faced and his frustrations, one can do little better than to read Wigner's memoir for the period (pages 24 to 130 of part A, volume V of Wigner's collected works) and the introductory essay by Alvin Weinberg preceding it. The experience left a permanent mark on Wigner, although he did admit later that the reactors built and operated by Dupont at Hanford in Washington state were highly successful.

When it became clear after the testing of the first atomic bomb at Alamogordo in July 1945 that the United States would soon possess an arsenal of nuclear weapons, Wigner joined a group of project scientists who requested that President Truman forego the use of such bombs in Japan. Although he was proud of his contribution to the release of nuclear energy, which he regarded as very important for the future of mankind, he was not comfortable that his work could also contribute to the death of many Japanese civilians. According to his daughter, he later found some solace in the thought that the use of the bombs had also shortened the duration of the war and thereby saved many lives on both sides.

DIRECTOR OF RESEARCH, CLINTON LABORATORIES, OAK RIDGE

Once the basic mission of the Chicago laboratory had been fulfilled and the war was nearing its end, Wigner began to make plans about the best way to explore peaceful uses of nuclear energy in the postwar period. He finally decided to spend a period in Tennessee as director of research at Clinton Laboratories, forerunner of Oak Ridge National Laboratory. A one-megawatt graphite research reactor had been constructed there in 1943 following the success of the Fermi test reactor. Initially, the laboratory at Oak Ridge had been under the management of the University of Chicago, however, it was turned over to the Monsanto Chemical Company at the end of the war.

Wigner planned a two-pronged approach. First, he would establish a training program in which some thirty-five young scientists and engineers could learn the principles involved in nuclear reactors. These individuals would become future leaders in reactor development. Second, he would assemble an expert team to design nuclear reactors that could produce useful power efficiently and as safely as possible, placing much emphasis on the so-called "breeder" reactor. A substantial part of his research team in Chicago, including Weinberg and Young, agreed to join him there and spend the next phase of their professional careers promoting the development of nuclear energy for peaceful purposes. A pithy account of the scientific and technical work carried out under Wigner's guidance during the year or so he was in residence at the laboratory is contained in Weinberg's introductory essay appearing in part A, volume V of the collected work mentioned above.

In the meantime, there was a great deal of legislative activity in Washington about the way the national nuclear energy program should be managed in peacetime. The debate was intense and protracted. The final result was the creation of a new civilian agency, the Atomic Energy Commission, which was put in charge of the operation on January 1, 1947. As the year progressed, Wigner eventually decided he was not really suited to serve as manager of a laboratory in such a complex, politicized environment. Many of the most important technical decisions would be made in Washington rather than in the laboratory. He left Oak Ridge at the end of the summer of 1947 and returned to Princeton to continue his academic career. Alvin Weinberg was eventually selected to be his successor. In the meantime, Wigner was pleased to serve as a valuable consultant to the laboratory.

In parallel with his continuing interest in the technology of nuclear reactors,[11] he became deeply involved with the problems of civil defense and spent much time at Oak Ridge working with a group that was interested in ways of achieving an effective level of defense as inexpensively as possible.

REMAINING ACADEMIC YEARS

On his return to Princeton University from the Clinton Laboratories, Wigner embarked on a long and fruitful period of research and graduate teaching. As mentioned above, he continued with his consulting on reactors and passionate involvement with civil defense. However, his main activity pertained to research, generally with his graduate students and research associates. Of Wigner's more than forty Ph.D. students, the large majority obtained their degrees during this postwar period. While he was perhaps not as venturesome as before the war, his style remained the same and his broad interests continued, particularly in nuclear physics, in the foundations of quantum mechanics, and in relativistic wave equations. He initiated and developed fully the R-matrix theory of nuclear reactions and became a founding father of the quantum theory of chaos. There was also much greater opportunity for him to engage in philosophical reflections and the writing of related essays during the decades of this period.

Wigner's deep interest in the foundations of quantum mechanics, especially the quantum theory of measurement, persisted longer than any of his other interests. It was already present in his "soliloquy" in the 1920s, as well as in his contributions to von Neumann's famous 1932 book on the mathematical foundations of quantum mechanics. It continued in his thoughts and published work until the end of his life. Wigner's monumental work on the representations of the inhomogeneous Lorentz group (1939) led after World War II to his work[12] with Newton on relativistic wave equations. Although this work enjoyed considerable success, important problems remained. Indeed, Wigner remained pessimistic until the end of his life about fully reconciling the present formulation of quantum mechanics with special and general relativity. Limitations on general measurability were pointed out in an important paper with G. S. Wick and A. S. Wightman.[13]

In the postwar years Wigner's interest in nuclear structure gradually waned, but his involvement in nuclear reactions grew and was, perhaps, responsible for more of his published work than any other subject. The various collective models for nuclear structure that gained popularity were not to Wigner's taste. However, he was deeply interested in understanding individual particle motion in nuclei and, with Vogt, used a method very similar to the Wigner-Seitz method for electron correlations in solids to show how the Pauli exclusion principle permitted the persistence of such motion despite the absence of a central field and despite the strength and short range of the nuclear forces.

The R-matrix theory of nuclear reactions arose out of Wigner's prewar work on the Breit-Wigner formula and has remained, for more than half a century, the most successful and widely used method for the description of resonance phenomena in nuclei. It was developed initially with Leonard Eisenbud,[14] but many other students and colleagues were involved in its elaboration. Wigner turned to it and its mathematics frequently.

The mathematics associated with R-matrices and R-functions fascinated Wigner beyond their direct application to resonance reactions. Although he remained a physicist throughout his life, deeply committed to the understanding of nature, he could be beguiled by mathematics. While contemplating the nature of the small random matrix elements involved in the myriad of compound nuclear levels encountered, for example, in the absorption of slow neutrons by uranium to produce slow fission, Wigner introduced an infinite Hermitian matrix that possessed random matrix elements. In this case the random matrix elements were related to the level widths involved in the problem. Using ideas he had gained from von Neumann, he was able to show[15] that a statistical distribution of level spacing still persisted in the midst of utter randomness. This "Wigner distribution" of spacing became a cornerstone of the quantum theory of chaos.

Perhaps because he was the individual who introduced the concept of symmetry into quantum mechanics and had developed well-entrenched concepts of how nature should behave, Wigner was quite taken aback when, in the mid-1950s experimental observations of the details of nuclear beta decay demonstrated that we live in a portion of the universe where inversion symmetry is not valid for the so-called weak interactions involved in such decay.

RETIREMENT

Although he retired as a professor of physics at Princeton University in 1971, Wigner's overall activities did not diminish. In fact, they broadened in important ways, since he was now relieved of some of the routine associated with academic life. Moreover, he was able, with essentially undiminished vigor, to focus as he wished on aspects of physics, philosophy, and technology that were of greatest interest to him personally. He continued his lifelong interest in the mathematical foundations of quantum mechanics with particular reference to the conclusions that could be drawn using the powerful techniques derived from group theory. Moreover, the gradual lightening of responsibilities as he approached retirement gave him the time to prepare the first edition of his collection of philosophical essays *Symmetries and Reflections*.[2] The increased freedom also permitted him to become more deeply involved in international meetings where broad issues related to science were discussed. This included, for example, the annual meetings of Nobel Prize recipients at a private estate on Lake Constance. He also became the leader of free-ranging philosophical discussion groups that met more or less annually under the auspices of the Unification Church.

To retain a link with the teaching side of academic life, he accepted appointments as visiting professor and lecturer at several institutions. Among the most prominent were a series of appointments in the physics department of the State University of Louisiana at Baton Rouge and in the summer school at Erice in Sicily.

He retained close consulting and working relations with his former colleagues at the Oak Ridge National Laboratory with special emphasis on research devoted to means of providing protection to civilians in the event of nuclear war. Linked to this, he devoted much attention to the work of the Federal Emergency Management Agency, which is responsible for preventing and providing emergency aid for national disasters.

Once signs of increasing personal and political freedom began to appear in his native Hungary, he resumed relationships with the cultural and scientific leaders there and encouraged the expansion of freedoms. In the process, he became something in the nature of a Hungarian national hero.

Wigner's vital forces began to display attrition for the first time only when he was well into his eighties, the principal sign being partial, but significant memory loss. He no longer traveled without a companion. Remarkably enough, he retained a fairly complete and detailed memory of matters related to science and technology long after he encountered difficulties in other areas.

In summary, Wigner laid the foundations for the application of symmetry principles to quantum mechanics, an achievement for which he earned the Nobel Prize. Based on these foundations, symmetry has come to play a central role in the development of physics during the second half of this century, granting that the developments have gone considerably beyond Wigner's own work. He was fond of symmetries, such as rotations in which observations remain unchanged when the symmetry transformation is applied uniformly to everything. He usually worked with quantum mechanical systems possessing a finite number of degrees of freedom in which the ground states exhibit the full symmetry of the physical system. In contrast, the ground state can be asymmetric in systems having an infinite number of degrees of freedom (that is, the symmetry is broken spontaneously). Theories involving spontaneously broken symmetries now underlie the description of magnetism, superconductivity, unified electroweak interactions, and many of the concepts employed in attempting to develop theories that will provide further unified understanding of the forces between fundamental particles. Posterity will long remember Wigner for giving powerful new tools to the theoretical physicist, as well as for his comparably basic work on the development of nuclear reactors.

NOTES

1. *The Collected Works of Eugene Paul Wigner.* New York: Springer Verlag:
Part A, The Scientific Papers. Vol. I: Eugene Paul Wigner: A Biographical Sketch; Applied Group Theory; Mathematical Papers. Vol. II: Nuclear Physics. Vol. III: Particles and Fields; Foundations of Quantum Mechanics. Vol. IV: Physical Chemistry; Solid State Physics. Volume V: Nuclear Energy.
Part B: Historical, Philosophical and Socio-Political Papers. Vol. VI: Philosophical Reflections and Syntheses. Vol. VII: Historical and Biographical Reflections and Syntheses. Vol. VIII: Socio-Political Reflections and Civil Defense.
As of December 1997, all part A volumes and vol. VI of part B are available. Volume VII of part B was to be released shortly.

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