NATIONAL ACADEMY OF SCIENCES

WARREN WEAVER

1894—1978

A Biographical Memoir by

MINA REES

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July 17, 1894–November 24, 1978

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INTRODUCTION

WARREN WEAVER died on November 24, 1978, at his home in New Milford, Connecticut. The New Milford house in the Connecticut countryside was a haven of beauty and peace. It had been conceived and planned and built with full concern for all the little details that were important to him and to Mary, his wife of many years, as they looked forward to the happy years together after Warren's retirement. They had been fellow students at the University of Wisconsin—she was Mary Hemenway then—and their marriage a few years after their graduation brought them an affectionate family life, shared by their son, Warren Jr. (and his family), and their daughter, Helen.

Warren Weaver started his career as a teacher of mathematics. But before his thirty-eighth birthday he became a foundation executive when he accepted the post of director of the Division of Natural Sciences of the Rockefeller Foundation. In that role he exercised a profound influence on the development of biology worldwide, and it was probably for this that he was best known during his lifetime. During his years as an officer of the Rockefeller Foundation, however, and during his service as an officer of the Sloan Foundation after his retirement from the Rockefeller post, his influence on many other aspects of science expanded and its impact was broadly felt.

Weaver assumed the vice-presidency of the Sloan Foundation immediately after his statutory retirement from the Rockefeller Foundation in 1959. But he reduced the amount of time he spent at his office so that he would have more time for his family and the extensive property at his New Milford home. He liked intellectual work, but he also loved to do physical work—chopping wood, moving rocks, gardening, puttering in his shop. He worked all the time: in a doctor's office (whether the wait was five minutes or half an hour) or on a commuter train—and he commuted regularly. He found these bits of time important. And he found the work that he was able to do in these moments very rewarding.

These personal qualities, combined with his great pleasure in working with and absorbing new ideas in physics and new results across a broad spectrum of scientific research, made possible his extraordinarily productive life. His performance as a philanthropoid (his term) was exemplary; in addition to the Rockefeller and Sloan Foundation positions, he also held responsible posts in the civilian scientific effort that supported the military services during World War II. After the war his achievements as an expositor of science gave him a distinctive role in the growing movement to promote the understanding of science on the part of the nonscientific public.

These are the main themes to which I shall devote this memoir.

CAREER CHOICE, ARMY SERVICE, AND MARRIAGE

Weaver was born on July 17, 1894, in the little town of Reedsburg, Wisconsin (population circa 2,000). As a child he was shy, introspective, unskilled in sports, and often lonesome. His fondness for his elder brother Paul, which became a warm and important part of both their lives, developed only after their graduation from college. Paul took a job in banking—as a result of parental pressure—but soon rebelled and pursued his own vocation, becoming an accomplished pianist–organist and ending his career as head of the School of Music at Cornell. Warren's career had a more intriguing genesis.

When Warren was a youngster, his father, who was a pharmacist, made an annual buying trip to purchase the drugstore's supply of Christmas toys for the coming holiday season. It was traditional for him to return with a gift for each of the boys. After one of these trips, Warren received a small electric motor that was powered by a dry cell. It was labeled "Ajax" and cost a dollar. As Warren wrote some sixty years later in a paper on careers in science:

> Within a few weeks I had built, with spools and similar household objects, all the little devices that could be run with the tiny torque of this motor. I took off the field winding, re-wound it—and it would still run! Getting more adventuresome, I took off the armature winding and discovered how it had to be put back on so as to recapture the miracle of movement.
>
> I promptly decided that this was for me. I didn't know any name to apply to this sort of activity—I didn't know (or care, I suspect) whether anyone could earn his living doing this kind of thing. But it was perfectly clear to me that taking things apart and finding out how they are constructed and how they work was exciting, stimulating, and tremendous fun.
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> It may well be the case that in the small rural village where I lived . . . there was not a single person who had any real concept of what the word "science" meant. I was accordingly told that this was "engineering"; and from that time until I was a junior in college, I assumed without question that I wanted to be an engineer.[1]

[1] Warren Weaver, "Careers in Science," in *Listen to Leaders in Science*, ed. Albert Love and James Saxon Childers (Atlanta: Tupper & Love/David McKay, 1965), p. 276.

It was at the University of Wisconsin that Warren—studying "Advanced Mathematics for Engineers"—realized that his enthusiasm was for science rather than for engineering. He decided to pursue a graduate degree in mathematics and theoretical physics as soon as this proved feasible. Immediately after receiving a degree in civil engineering in 1917 (he had earned a B.S. in mathematics in 1916), he accepted an invitation from Robert A. Millikan to become an assistant professor of mathematics at Throop College (soon to be renamed the California Institute of Technology). Millikan was just shifting his interests from Chicago to Pasadena and was planning to spend one academic quarter there each year. Max Mason, a brilliant mathematical physicist who had been Weaver's teacher and close friend at Wisconsin, suggested Weaver to Millikan. Mason and Charles Sumner Slichter, professor of applied mathematics at Wisconsin, were the two professors who most influenced Weaver's choice of a career. Mason would continue to be an important influence in his life in the years immediately ahead.

Weaver had been at Throop for less than a year when he was drafted into the Army at the request of Charles E. Mendenhall, chairman of the Physics Department at Wisconsin. Mendenhall was then serving as a major in the Army's unit associated with the newly formed National Research Council. Weaver was assigned to participate in one of the technical efforts, carried on chiefly at the National Bureau of Standards, to develop effective equipment to assist U.S. aviators in the air battles of World War I. He was discharged as a second lieutenant in about a year. After a brief interlude teaching at Wisconsin, he returned to Pasadena—but not before marrying Mary Hemenway and taking her back with him.

THE LIFE OF A PROFESSOR OF MATHEMATICS

The next year at Pasadena was delightful and stimulating. But in the spring of 1920, as the end of the academic year approached, a letter from Madison invited Weaver to join the faculty at Wisconsin. There was also a most important letter from Max Mason, who urged Warren to accept Wisconsin's offer and suggested that they work together on a book on electromagnetic field theory. For Warren this was irresistible—the opportunity to collaborate with Mason, whose insights, brilliance, and imagination he so greatly admired. And his own power as an expositor would be given full rein because Mason had no fondness for committing ideas to paper.

By the fall of 1920, the newlyweds were established in Madison, where they were to remain for the next twelve years. In 1921 Warren earned his Ph.D. His collaboration with Mason began promptly and was vigorously pursued. In 1925, however, Mason left to become president of the University of Chicago, while Weaver carried on alone in Madison, sending drafts to Mason in Chicago. In 1928 Weaver succeeded Edward Burr Van Vleck as chairman of the Department of Mathematics.

The Mason–Weaver book, *The Electromagnetic Field,* was published in 1929. For some years thereafter, it was the book from which many graduate students in physics learned Maxwell's field equations and the associated theory. For occasional physicists whom he met in later years, Warren Weaver became "Weaver, of Mason and Weaver."

Although his most important writing in the years at Madison was the collaboration with Mason, Weaver also published occasional papers in mathematics, chiefly in probability theory and statistics, subjects for which he continued to have great enthusiasm throughout his life. And in 1924 he published—jointly with Max Mason—what he called "a really good mathematical paper" that turned out to contain the fundamental analytical theory of the supercentrifuge.

The publication in 1963 of *Lady Luck,* his little book on probability, is an indication of his continuing interest in the subject and of his conviction that it should be accessible to laymen, particularly young students. *Lady Luck* is an instance of Weaver's rare gift of exposition. But his own estimate of most of the mathematical papers he published during his stay at Wisconsin was that they were routine solutions of specific problems, not real additions to mathematical knowledge. He complained that he never seemed to get a first-class original idea for advancing mathematics itself.

THE LURE OF THE ROCKEFELLER FOUNDATION

In 1931 a disturbing and unexpected invitation arrived from Max Mason, an invitation that raised the possibility of Weaver's leaving what he and his wife considered a nearly idyllic life in Madison. Mason had left the presidency of the University of Chicago in 1928 to take on responsibility for the work in the natural sciences that was supported by the Rockefeller Foundation; in 1930, he assumed the presidency of the foundation. In the fall of 1931, Mason invited Weaver to come to New York to discuss the possibility of his joining the staff of the Rockefeller Foundation as head of its program in the natural sciences. Weaver was reluctant to accept the invitation for many reasons. But the fact that it came from Mason and included a free trip to New York (which he had never seen) settled the matter. Weaver was off to New York.

The city itself proved at least as alluring as he had imagined—and the visit to the Rockefeller Foundation as tempting. Here we must stop to consider, on the one hand, the organizational situation in the Rockefeller Foundation at that time and, on the other hand, the ideas about the state of science that had been brewing on many of the country's campuses in the late 1920s and early 1930s.

On the campuses there was talk that the century of biology was upon us. At Wisconsin, for example, there was a lively program in biology at the School of Agriculture as well as in the College of Arts and Sciences. Mason and Weaver had often discussed a new thrust in biology and the opportunities that would open up if some of the most imaginative physical scientists turned their attention—and some of the sophisticated instruments they had developed—to the examination of biological problems. Weaver complained about the lack of really good ideas in the biological literature and its failure to produce the intellectual ferment characteristic of much of the work in the physical sciences. At the time of his first visit to New York, he hoped to interest the trustees of the Rockefeller Foundation in a substantial shift in direction: he wanted to bring to reality a change in the major thrust of biological research worldwide—no mean ambition. Happily, his timing was fortuitous.

The Rockefeller Foundation had recently been reorganized, absorbing several other Rockefeller agencies that had been founded for special purposes that no longer required separate settings. The foundation's aim, "to promote the well-being of mankind throughout the world," was interpreted by the trustees as being best served, in the immediate future, by the support of the scientific research of individuals. (This contrasted with their practice in the immediate past, when large sums were spent on plant and endowment, chiefly at a few major institutions, or on the funding of new research establishments such as the Woods Hole Oceanographic Institution.)

The newly created Division of Natural Sciences thus would be faced with deciding how "the well-being of mankind throughout the world" could best be served through the support of science. The amount then available—roughly $2 million a year—was substantial; in 1932, it constituted a large percentage of the funds available for the support of research in the United States. But although the funds available were substantial, they were nonetheless limited, particularly since the foundation defined its program in the natural sciences as concerned broadly with anything that was science but not medicine. Some principles of selection would need to be established.

In the discussions with the trustees on his visit to New York, Weaver was asked for his ideas on the Rockefeller program for the support of scientific research. He expressed his satisfaction with his own experience in the physical sciences, a field that had been a principal beneficiary of Rockefeller support. But he also stated his conviction that the most striking progress in science would soon occur in the biological field. There, he thought, the Rockefeller Foundation would have a great opportunity. He urged that it undertake a long-range program of support of quantitative biology—a program that would seek to apply to outstanding problems of biology some of the methods and machines that had been so successful in the physical sciences.

Although he urged his point of view with his customary persuasiveness, Weaver also insisted that he was not the man to preside over the proposed program; he was, after all, not trained as a biologist. He did, however, have the background in the physical sciences that he himself had argued should be brought into the picture; and he returned to Madison with an invitation to become the director of a newly defined Division of Natural Sciences of the Rockefeller Foundation. Thus he and his wife were faced with the difficult decision that made so complete a change in their lives. In his autobiography, Weaver says of one of the elements in their decision:

I think . . . that I was both realistic and accurate about my abilities and my limitations. I loved to teach, and knew that I had been successful at it. I had a good capacity for assimilating information, something of a knack for organizing, an ability to work with people, a zest for exposition, an enthusiasm that helped to advance my ideas. But I lacked that strange and wonderful creative spark that makes a good researcher.

Thus I realized that there was a definite ceiling on my possibilities as a mathematics professor. Indeed, I think I realized that I was already about as far up in that profession as I was likely to go.[2]

THE PROGRAM IN EXPERIMENTAL BIOLOGY

After much soul-searching, the Weavers decided that the opportunities opening up in New York could not be refused. In January 1932, Weaver was elected director for the natural sciences of the Rockefeller Foundation.

Shortly thereafter, Weaver translated the discussions that had led to his appointment into a formal proposal to the trustees. In it he suggested that the foundation's science program be shifted from its previous preoccupation with the physical sciences to an "interest in stimulating and aiding the application, to basic biological problems, of the techniques, experimental procedures, and methods of analysis so effectively developed in the physical sciences." The trustees adopted this recommendation.

Commenting on this action, Dean Rusk—president of the foundation from 1952 to 1960—wrote in his introduction to the 1958 president's report (the last before Weaver's retirement):

In 1932–33 The Rockefeller Foundation elected to center its major scientific effort in the sciences concerned with living things. . . . [This] major emphasis . . . which continues to characterize the Foundation's science program, rested upon four considerations. First, [the life sciences] could

[2] Warren Weaver, *Scene of Change, a Lifetime in American Science* (New York: Charles Scribner & Sons, Inc.), p. 62.

be expected to add significantly to a better understanding of man himself, whose well-being is a basic charter concern of the Foundation. Second, the life sciences were intimately linked with medicine and public health, the central interests of the Foundation in its opening decades. Third, in the early 1930's the several sciences concerned with living things seemed to be poised for a historical surge forward, with exciting possibilities opening up in all directions. Finally, it seemed at the time that the life sciences were not receiving the public interest and financial support which were warranted by their intellectual promise and by their potential capacity to contribute brilliantly to man's practical needs. The decisions gave The Rockefeller Foundation a modest share in a great adventure which is continuing to unfold.[3]

The trustees' decision involved a major change in the modus operandi of the foundation. In 1933 the program statement formulated for the Natural Sciences Division articulated this change and set forth these general principles to provide the desired direction as well as the necessary flexibility to the program of the division:

A highly selective procedure is necessary if the available funds are not to lose significance through scattering. In the past, this selection has consisted chiefly of a choice of scientific leaders, among both men and institutions, although there has always been some selection on the basis of fields of interest. It is proposed, for the future program, that interest in the fields play the dominant role in the selection process. Within the fields of interest, selection will continue to be made of leading men and institutions.

In general, this narrowing of purpose in the specialized program should result in greater emphasis on the biological and related fields, and especially in greater emphasis on the study of man himself.

A small provision should be made in the budget of the program to care for unpredictable but unquestionable opportunities.

The program should always be kept flexible.

The immediate and underlying values in science justify a continuation of general support to the development of science.[4]

[3] The Rockefeller Foundation, *President's Review and Annual Report, 1958* (New York: The Foundation), p. 5.

[4] The Rockefeller Foundation, *President's Review and Annual Report, 1958*, p. 26.

Progress with the program was so prompt and promising that the foundation's 1938 annual report began its natural science section with a sixteen-page discussion headed "Molecular Biology." It began: "Among the studies to which the Foundation is giving support is a series in a relatively new field, which may be called molecular biology, in which delicate modern techniques are being used to investigate ever more minute details of certain life processes." This was probably the first use of the term *molecular biology*.

Some years later (1949), Weaver expressed his confidence in the importance of the research going on in molecular biology:

> The century of biology upon which we are now well embarked is no matter of trivialities. It is a movement of really heroic dimensions, one of the great episodes in man's intellectual history. The scientists who are carrying the movement forward talk in terms of nucleoproteins, of ultracentrifuges, of biochemical genetics, of electrophoresis, of the electron microscope, of molecular morphology, of radioactive isotopes. But do not be misled by these horrendous terms, and above all do not be fooled into thinking this is mere gadgetry. This is the dependable way to seek a solution of the cancer and polio problems, the problems of rheumatism and of the heart. This is the knowledge on which we must base our solution of the population and food problems. This is the understanding of life.[5]

With the passage of time, Warren Weaver's career involved him in major responsibilities far from molecular biology, both during World War II and afterward, but he continued his enthusiasm for research in this field. In 1970 he wrote in his autobiography:

> I believe that the support which the Rockefeller Foundation poured into experimental biology over the quarter century after 1932 was vital in encouraging and accelerating and even in initiating the development of

[5] Letter from Warren Weaver to Mrs. J. M. H. Carson, June 7, 1949. Published in Raymond B. Fosdick, *The Story of the Rockefeller Foundation* (New York: Harper & Brothers, 1952), p. 166.

> molecular biology. Indeed, I think that the most important thing I have ever been able to do was to reorient the Rockefeller Foundation science program in 1932 and direct the strategy of deployment of the large sums which that courageous and imaginative institution made available. It was indeed a large sum, for between 1932 and my retirement from the Rockefeller Foundation in 1959 the total of the grants made in the experimental biology program which I directed was roughly ninety million dollars.[6]

Weaver, however, also sought some objective basis to support his view that the Rockefeller Foundation program for the support of molecular biology played an important role in the emergence of this field as one of the most exciting in present-day science. He reported that George Beadle, in the late 1960s, identified eighteen Nobel laureates between 1954 and 1965 who had been involved in one or another aspect of molecular biology; fifteen had received assistance from the Rockefeller Foundation. Weaver remarks, sagely, that what was significant was not that they received this assistance, but that they received it, on the average, more than nineteen years before the Nobel prize was awarded.

Weaver's assessment of the excellence and importance of the Rockefeller Foundation program was shared by the trustees and by the scientists whose work gave the program its shape and significance. These scientists have commented on the importance of the support they received and on the skill and understanding with which it was given. Such comments are, of course, hard to assess. One of the most persuasive was made by Max Delbruck, a physicist turned biologist, in a letter to Weaver in 1967: "I can only testify as far as I am concerned, and here very strongly and unambiguously: without the encouragement of the Rockefeller Foundation received in 1937 and their continuing support through the mid-forties I believe I would hardly have been able to make my contributions to biology."[7]

[6] Weaver, *Scene of Change*, p. 72.
[7] Weaver, *Scene of Change*, p. 74.

It seems clear that the procedures Weaver developed for identifying the most promising young men in Europe and America and providing them with support before their quality was generally recognized were strikingly effective. Weaver's establishment and management of the Rockefeller Foundation's program in molecular biology accelerated the movement of physicists and chemists into biology and was of major significance for the development of biology.

Robert E. Kohler, a historian of contemporary science, had this to say in an article in *Minerva* about the decision that was reached by the trustees of the Rockefeller Foundation in the early 1930s concerning their program in the natural sciences:

> In the United States the large private foundations, most notably the Rockefeller Foundation, pioneered in establishing the general institutional traditions and the specific administrative techniques for the patronage of individual research on a large scale. Warren Weaver's programme in the natural sciences division of the Rockefeller Foundation in the 1930s is an exemplary case of this new relationship between a promoter of science and academic scientists. Weaver played an active role in selecting areas of research to be developed, yet he did not intrude on the actual process of research. He developed research grants for individuals and projects and mastered the art of conducting a large programme of relatively modest grants—skills which Foundation leaders doubted could be perfected. The organization and style of the programmes of the Rockefeller Foundation played a significant role in forming the mode of operation of federal science agencies after the Second World War.[8]

THE PUBLIC UNDERSTANDING OF SCIENCE

While he was still at Wisconsin, Weaver had begun a program of self-education in biology because he was convinced that the most exciting developments in science in the years

[8] Robert E. Kohler, "A Policy for the Advancement of Science," *Minerva: A Review of Science, Learning, and Policy*, vol. 16, no. 4(Winter 1978):480–81.

ahead would lie in that field. The limitations imposed by his inability to conduct the experimental program that was so essential to an adequate education in biology were somewhat mediated by his transfer to the Rockefeller Foundation. There his close identification with the often inspired experimental work of his many associates in Rockefeller-supported research in molecular biology provided him with a rare education in the character and status of work in that field. This background and his experience in administering the Rockefeller Foundation program were called upon by the National Academy of Sciences in 1955.

The country's newspapers during that time had been persistently asking, "What effects will the atomic age have on the human race?" The public was hopelessly confused by the conflicts of opinion being expressed by people it viewed as qualified specialists. At a meeting of the Board of Trustees of the Rockefeller Foundation in 1954, several members asked whether there was any way in which the foundation could help to clear up the confusion. Consequently, the Board asked one of its members, Detlev W. Bronk, who was at that time president of the National Academy of Sciences, whether the Academy would be willing to address itself to some of the scientific aspects of this question. Would the Academy be willing to carry out a survey of the biological effects of atomic radiation and prepare a report that would set forth the best information then available in a form accessible to seriously concerned citizens?

After consulting his colleagues at the Academy, Bronk agreed to undertake the study. He appointed six committees: genetics, pathology, meteorology, oceanography and fisheries, agriculture and food supplies, and disposal and dispersal of radioactive wastes. The first committee was chaired by Weaver, who successfully mediated the opposing positions of the two groups of geneticists who were members of the committee and prepared a report that had their unanimous support. After the first summary report was published in 1956, there was virtual editorial unanimity in the nation's newspapers that "the report should be read in its entirety to be appreciated" and that it deserved the close attention of all concerned citizens.

In 1957, the National Academy of Sciences announced the award of its Public Welfare Medal to Warren Weaver "for eminence in the application of science to the public welfare." The statement that was issued said, in part:

> Dr. Weaver . . . has recently performed . . . a task of immense significance to the general public. Making use of his unusually broad scientific experience in mathematics and biology, Dr. Weaver served as chairman of a committee of distinguished geneticists asked by the Academy to appraise the genetic effects of atomic radiation.
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> That the committee's report, published in 1956, was able to fashion the various points of view expressed by geneticists into agreement on most of the fundamental issues has been attributed, in large measure, to the leadership, breadth of vision, and insight contributed by Dr. Weaver. The summary report of the Academy committee has been generally accepted in the United States as an authoritative assessment of the genetic hazards involved in atomic radiation.

Weaver's leadership in preparing this report was one of his most widely acclaimed contributions to the public understanding of science, but he made other such contributions with possibly more far-reaching results. One of his major efforts in his continuing commitment to the promotion of the public understanding of science was undertaken toward the end of World War II. At that time the U.S. Rubber Company was sponsoring the Sunday afternoon radio broadcasts of the New York Philharmonic Symphony Orchestra. They asked Weaver to serve as chairman of a committee of scientists who would undertake to provide an intermission program. U.S. Rubber was committed to the idea that these discussions should treat material of substantial concern to a public whose anticipation of the end of the war was darkened by anxiety about the future. As Weaver said: "What the future would be, no one could forecast. But one thing was sure: science would be a mighty and pervasive force in helping to shape that future. . . . The time had clearly come when everyone ought to have a broader and a more authentic understanding of what science is and how it operates."

The committee assembled by Weaver provided seventy-nine intermission talks, each given by a research scientist who cited his own work. These talks treated a wide range of sciences as well as the relations of science to such things as health, war, and the values of our society. In 1947 these talks were assembled in a book, *The Scientists Speak,* which was edited by Weaver.

Nearly a decade later, Weaver arranged a comparable series for television for the Bell Telephone Science Series. Once again he recruited a committee of scientists who planned a series of eight television programs. Each program dealt with a single field such as genetics or astronomy. The committee's work continued from the fall of 1954 until the fall of 1963. Each program was broadcast twice on a national network, and copies of the filmed programs were distributed free of charge to schools, colleges, clubs, churches, and other groups. The total viewing audience for each program was estimated at more than 60 million people.

These are but two instances of the variety of ways in which Weaver participated in formulating public statements about science—the kind of statements that have appeared with increasing frequency in recent years. In fact, Weaver himself played an important role in bringing about this increased public attention to developments in science. During his membership on the Executive Committee (now called the Board of Directors) of the American Association for the Advancement of Science, the decision was made to reexamine the association's policy and program of activities. The object of this reexamination was to attempt to achieve a better fit between these activities and the changing situation of science in the United States. It was Weaver who formulated a statement for the AAAS membership that expressed the Executive Committee's hopes for a conference on this subject to be held at Arden House in September 1951; it was Weaver who drafted the "Arden House Statement of Policy for the AAAS"; and, after he was elected president of AAAS, it was Weaver who implemented the Arden House recommendations.

Although the Arden House conference in no sense changed the objectives of AAAS—objectives that had long been a part of its constitution—it did change the emphasis that was placed on some of these goals. One of the changes was the role assigned to programs to increase public understanding and appreciation of the importance and promise of the methods of science in human progress. In his retiring presidential address at a AAAS meeting on December 28, 1955, Weaver said:

> It is hardly necessary to argue, these days, that science is essential to the public. It is becoming equally true, as the support of science moves more and more to state sources, that the public is essential to science. The lack of general comprehension of science is thus dangerous both to science and to the public, these being interlocked aspects of the common danger that scientists will not be given the freedom, the understanding, and the support that are necessary for vigorous and imaginative development.

The variety of ways in which AAAS has succeeded in implementing this new emphasis in its purposes would not be appropriately summarized here. But it is appropriate to mention that Warren Weaver became the first chairman of the AAAS Committee on the Public Understanding of Science and was influential in organizing the Council for the Advancement of Science Writing. Moreover, the AAAS magazine *Science* has provided a training ground for a group of gifted science writers. In many ways the Weaver influence has been felt in the excellent science reporting now seen in U.S. newspapers, journals, and broadcasts. In particular, in the late 1940s, he was an enthusiastic supporter of Gerard Piel and Dennis Flanagan who undertook to convert the long-established *Scientific American* into a vehicle for reporting on recent important scientific results—using the scientists themselves as the prime reporters.

Piel and Flanagan had been science editors on the staff of the magazine *Life* and viewed the intermission talks on science that Weaver had arranged for the New York Philharmonic Symphony performances as a model worth emulating. They planned to use his method: to get the scientist to tell the story and then to help him retell it, using their skills in communicating with a nonscientific public to "pool two relevant competences," a Weaver description.

Financially, the magazine barely survived the period after they had gotten it "off the pad," but before long it was safely in the black. With Weaver's continuing help, the venture capitalists who had originally backed the enterprise were induced to continue their support until the magazine had established itself. It is now, arguably, the source of firsthand information about new scientific work that is most respected by nonscientists.

Weaver was widely recognized for his activities "at the interface of science and society" (as he described it). In a single year—1965—he received the two most prestigious prizes awarded for contributions to the public understanding of science. The first, the Kalinga Prize, was awarded for literary excellence in scientific writing by an international committee set up by UNESCO. It was established through the generosity of one of India's industrial leaders, B. Patnaik, to honor particularly meritorious contributions to the popularization of science. Weaver was the last winner of that prize and the first winner of the Arches of Science Award, which was intended to stimulate "the interpretation of what science as a high form of intellectual activity means to man and to the society and the world in which he lives and works and dreams and thinks." The citation that accompanied the Arches of Science Award concluded with a quotation from Weaver's own writings:

> As a natural social activity science belongs to all men. It is well for us that this is true. For it tells us that science need not be regarded as the possession of some select inner priesthood, but that its essential nature can be understood by all literate persons. This is the proposition which assures that the citizens of a free democracy, understanding and prizing the work of science, will provide the support and terms of support that will cause science to prosper and bring its benefits, power and beauty to the service of the people.

THE SLOAN FOUNDATION

Weaver's great facility in making scientific issues accessible to nonscientists was related to his enjoyment of words, his skill in using them, and his consistent willingness to be the member of a committee or board who wrote the summarizing statement or the final report. He was a member of the Board of Trustees of the Sloan Kettering Institute for Cancer Research and chairman of its Committee on Scientific Policy; as such, he regularly presided over the committee's detailed study of recommendations submitted for board action and presented the committee's findings on relevant scientific issues to the board. The majority of board members, including Alfred P. Sloan, Jr., were nonscientists. The effectiveness of Weaver's presentations and his success in coupling the institute's research with its clinical work were impressive—and Sloan was one of those who was most impressed. It was through increasingly frequent contacts of this kind that Weaver became one of Sloan's most trusted advisers.

In 1959, at the time of Weaver's retirement from the Rockefeller Foundation after nearly thirty years of service, he began a much shorter career as vice-president of the Sloan Foundation. Although Alfred P. Sloan's ideas and energy continued to dominate the foundation's program, Weaver was able to set up an internal structure under which the work of the foundation proceeded smoothly after Sloan's death in 1966. Weaver had retired as vice-president and a member of the foundation's board in 1964. At that time the board acknowledged its good fortune in having been able to call on his extraordinary experience and judgment in the practice of the arts of philanthropy and on his uncommon imagination and integrity. Board members also expressed their gratitude for his role in giving them a keener sense of the meaning and responsibilities of truly professional philanthropy. And they emphasized the enduring value of his broad view of the importance of science to our national life and his conviction that the beauty and power of science are meant to elevate the human condition in both an aesthetic and a practical sense.

One of Weaver's most gratifying activities during his Sloan years resulted in the construction (with partial support from the Sloan Foundation) of a building at New York University that was christened Warren Weaver Hall. This building houses the now-famous Courant Institute of the Mathematical Sciences, the second such institute created through the imagination and drive of Richard Courant. His energetic leadership at Göttingen, Germany, before World War II, was supported by the Rockefeller Foundation: it resulted in the establishment of the world-renowned Göttingen Mathematics Institute, which suffered severely during the Hitler regime. The Courant Institute at New York University is a worthy companion to the Institute at Göttingen.

TWO PAPERS OF SPECIAL INTEREST

Weaver combined his enjoyment of words with his enthusiasm for statistics and probability theory in two efforts that were of particular interest to him: an article entitled "Recent Contributions to the Mathematical Theory of Communication" and a memorandum on machine translation, both published in 1949. The first made Claude E. Shannon's work in communication theory available to a larger audience than could be reached by Shannon's more technical presentation. The memorandum, "Translation," is credited by William N. Locke and A. Donald Booth (in their book[9] on the subject, which was published in 1955) with providing the original stimulus to the field of machine translation. Weaver himself believed that this second paper embodied one of the two or three ideas he ever had that were both original and important.

There was a good deal of work in the field worldwide in the early 1950s. In the United States, part of this work had Rockefeller Foundation support, and much of it had government support until the mid-1960s. At that time the so-called Pierce Report[10] suggested that the field of machine transla-

[9] William N. Locke and A. Donald Booth, eds., *Machine Translation of Languages* (New York: Wiley Technical Press, 1955), p. 15.

[10] Division of Behavioral Sciences, National Academy of Sciences–National Research Council, *Language and Machines: Computers in Translation and Linguistics. A Report by the Automatic Language Processing Advisory Committee*, NAS–NRC Publication no. 1416 (Washington, D.C.: NAS–NRC, 1966). The *Recommendations* of the NAS–NRC Automatic Language Processing Advisory Committee are given on p. 34. The main thrust of the Advisory Committee's position on fully automatic translation is suggested on p. 24 of the report, where significant invited comments by Victor H.

tion would be unproductive in the foreseeable future and that government support should be redirected to the support of linguistics as a science. As a result, the use of computers for natural-language processing became and continues to be a lively subfield of linguistics. Lately, however, research in machine translation has been attracting renewed attention. Current interest at the universities is in the use of artificial intelligence techniques applied to machine translation problems, and there is also work going on in industry.

THE WAR YEARS

From the beginning, Warren Weaver's duties at the Rockefeller Foundation required fairly regular travel to Europe—and later to other parts of the world. During his trips in the early 1930s, he became acquainted with many of Europe's leading scientists whose work lay in the areas of the foundation's interest. His conversations with German scholars in those years convinced him of the imminence of worldwide conflict.

In 1940, at the invitation of President Roosevelt, Vannevar Bush set up an organization, the National Defense Research Committee (NDRC), to aid the military services with their scientific problems. Weaver wrote to Bush, offering his services on a full-time basis. He also took a step motivated by his memory of World War I and the destruction of European libraries that ensued. With the support of the Rockefeller Foundation trustees, he arranged for the American Library Association to administer a grant "for the purchase or reproduction of American scholarly journals for institutions in areas of war damage, chiefly in Europe and Asia." A first-rate librarian was employed, and a large empty loft was

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Yngve, then of the MIT Research Laboratory of Electronics, are also quoted. Appendix 19 on pp. 121–123 deals with machine translation and linguistics.

rented in Washington. The librarian made a list of university libraries in Europe and the developing countries, including those with Socialist governments—the total was around 5,000—and entered subscriptions to all the professional journals in the United States. As the journals were published, copies were deposited in bins marked "Library of the Sorbonne," "Library of the University of Heidelberg," "Library of the University of Louvain," and so on. At the end of the war, the complete series of journals was boxed and ready for shipment to these libraries as the rubble was being cleared.

In July 1940, Bush invited Weaver to set up the fire-control section of NDRC. Weaver accepted and planned to resign from the Rockefeller Foundation. But he was persuaded to retain his appointment there, carrying on some of his usual duties while giving first priority to NDRC functions.

In fact, Weaver had few opportunities to perform Rockefeller functions, but those that occurred were important. One such opportunity during a wartime mission to England in the spring of 1941 proved of exceptional importance. Weaver received a note from Howard Florey of Oxford, saying that he would like to call on Weaver in London. Florey had begun experiments with molds—experiments that ultimately led to the production and widespread use of penicillin. At that time Florey and his colleagues could only produce very small amounts of a mold from which they were obtaining an important active ingredient. Florey was convinced that this ingredient had antibiotic properties so effective that it might play a major role not only in general medicine after the war but also, perhaps, in the immediate medical emergencies of the war. But it was impossible to produce larger amounts of the mold in England because resources were so completely taken up with pressing war needs. Florey hoped to get to the United States and persuade one or more of the American companies with large resources for handling fermentation problems to cultivate enough of the organism to permit the necessary human tests and eventually the practical application of the drug. Weaver undertook to arrange to finance the trip, Florey got permission from the British authorities to leave, and the rest is history. The Rockefeller Foundation continued its association with Florey after the war.

Meanwhile the NDRC fire-control section headed by Weaver was working on sighting systems to be used for directing the guns of an airplane against enemy aircraft and on bombsights for such uses as low-level attacks on submarines. But the largest and most useful of the projects sponsored by the section was the design and development of a successful electrical antiaircraft director.

For Army Ordnance, the most pressing problem when the war began was to furnish good fire control for a weapon that was capable of shooting down high-altitude planes. The mechanical methods based on gears and cams that had been used previously were neither rapid enough nor accurate enough to cope with the fast, high-flying targets of World War II. It was evident that a new approach was needed.

Bell Telephone Laboratories came forward with a novel concept: they would develop an electrical gun director whose computation process would rely on several electrical devices, none of whose designs had been proven. A compensating feature, however, was the expectation that the electrical instrument could be produced in large numbers by comparatively unskilled labor. This was in contrast to the existing requirements for precision machine tools and machine-tool skills in the manufacture of precision equipment using gears and cams.

After a conference between the fire-control section's executive committee and personnel at Bell Laboratories, Weaver made his recommendation: he advised the technical staff of Army Ordnance, traditionally skeptical about the use under battle conditions of anything electrical, to proceed with the proposed director. Finally, on November 4, 1940, Ordnance requested NDRC to begin work and to take all responsibility for technical supervision and direction. Work on the electrical antiaircraft director continued throughout 1941. In February 1942, the revolutionary instrument was accepted by the Army as the M-9 Director. It was ready in time to join radar and the proximity fuze, which was also developed by Bush's organization, in reversing the tide of the Battle of Britain—saving London from the worst of the destruction threatened by the German "buzz-bombs" that began to rain down on the city on June 12, 1944.

By late 1942, Bush had identified the increasing need for sophisticated mathematical studies, and the greatly expanded need for mathematical assistance in NDRC. He established the Applied Mathematics Panel (AMP) with Weaver as its chief; Harold Hazen of MIT became chief of the fire-control division.

The Applied Mathematics Panel was in need of a large group of mathematicians to provide assistance in military research. To meet this need the panel invited the participation of a broad array of able mathematicians, without regard to their field of specialization.

Several hundred mathematicians, whose peacetime work was often in the purest of "pure" mathematics, worked in groups set up at ten universities across the country to help with AMP problems. In these efforts the groups demonstrated both versatility and effectiveness in meeting military requirements, qualities that were much admired by the military officers with whom they worked. This was true also of the economists and others skilled in statistical techniques who joined in the work of the panel. Many of those associated with the panel left their own universities to join in the effort. The problems ranged from those calling for mathematical expertise even though they involved no new mathematical results (e.g., some problems dealing with optimum employment of equipment) to those requiring the creation of a new theory (e.g., inspection sampling of materials that were destroyed during testing—sequential analysis was born during World War II). Later, a number of these wartime developments in mathematics were enhanced by the postwar growth of federally financed research. Such research encouraged further exploration of some wartime beginnings, such as operations research and computer construction and use, and expanded the ongoing mathematization of a number of fields.

Warren Weaver's skill in the administration of research and his effectiveness in dealing with military officers and with the Washington bureaucracy greatly facilitated the work of the Applied Mathematics Panel. During the war, the panel received many letters of appreciation from military commands; at war's end, several of the war-born research projects were continued with support from interested military agencies. Weaver continued to serve on boards and commissions in Washington, including the Naval Research Advisory Committee (he was its first chairman), the War Department Research Advisory Panel, and the Research and Development Board of the U.S. Department of Defense. For his war work, he received the British King's Medal for Service in the Cause of Freedom and the Medal for Merit of the United States. In 1950 he was made an Officer of the Legion of Honor of France. The citation that accompanied the award of the U.S. Medal for Merit read, in part: "He revolutionized antiaircraft fire control. He made brilliant contributions to the effectiveness of bomber aircraft. The work of his Panel showed the full possibilities of the application of mathematics to the problems of war."

In 1952, in a reorganization of the Rockefeller Foundation, Weaver's responsibilities were enlarged when he was appointed vice-president for the natural and medical sciences. It was at about this time that he became active on several committees dealing with medical research. In 1952 he was also chairman of the board and nonresident fellow of the Salk Institute for Biological Studies; and in 1954 he was president of AAAS. He was a member of the American Philosophical Society (elected in 1944), a fellow of the American Academy of Arts and Sciences (1958), and a member of the National Academy of Sciences (1969). From 1956 to 1960 he served on the National Science Board.

During the war years the Rockefeller Foundation embarked on its major program to address the problems of hunger around the world. This work was the beginning of the effort that expanded from Mexico to a broader base in Latin America, Asia, and Africa and has been referred to as the "Green Revolution." For several years the Rockefeller Foundation called this program the "Conquest of Hunger," and it is still committed to a major undertaking to help improve agriculture-led development in Third World countries.

The agriculture program was initiated in 1941 after Raymond B. Fosdick, then president of the Rockefeller Foundation, returned from a visit to Washington. During the visit he had lunched with Henry A. Wallace, vice-president of the United States and an agricultural expert. Wallace had been appalled by the inferior quality of the cornfields he had just seen in Mexico, particularly because corn holds so central a position in the Mexican diet. He remarked that if anyone could increase the yield per acre of corn and beans in Mexico, it would contribute more effectively to the welfare of the country and the happiness of its people than any other plan that could be devised. Fosdick consulted Weaver about the possibility that the foundation could do something useful.

An extensive preliminary study was carried out by a group of three specialists—E. C. Stakman (plant pathology), Richard Bradfield (soils), and Paul Mangelsdorf (corn genetics and plant breeding)—who visited all the regions of Mexico at the request of the Rockefeller Foundation. They determined that a great deal could be done and outlined basic principles for the conduct of the work. After careful preparation the project was set up in Mexico in 1942 with the participation of the Mexican government; it was headed by J. George Harrar.

The work in Mexico prospered, and in 1950 a similar program was established in Colombia. Then Chile and other Central and South American countries entered the program. Improved varieties of wheat were bred in Mexico and successfully introduced into a number of African and Asian countries. With the cooperation of the Ford Foundation, an International Rice Research Institute was created in the Philippines on land furnished by the Philippine government. Sturdy, high-yielding rice was successfully bred there and distributed widely in Asia.

Commenting on the dwarf wheat strain developed in Mexico and the improved rice strain developed in the Philippines, an editorial in *Nature* (August 10, 1968) said, "They have provided countries which were perennially faced with starvation with the means not only to become self-sufficient, but equally important, to regain their self-respect and national pride."

Although Warren Weaver had continuing contact with this program during the war, his associates in the Rockefeller Foundation assumed the principal day-by-day responsibility. At the end of the war, after he had recovered from radical surgery necessitated by repeated and painful attacks of Ménière's disease, he devoted much of his time and energy to this expanding agricultural program. In 1970, looking back on his nearly thirty years of service to the Rockefeller Foundation, he expressed satisfaction at having been associated with two programs, "in both of which I had the privilege of major administrative responsibility: the program in experimental biology which played a significant role in initiating and developing the present-day field of molecular biology; and the agricultural program."[11]

OTHER ENTHUSIASMS

This account has focused on Warren Weaver's professional career over a period of nearly fifty years. Although his professional life was demanding, he had many hobbies, one of which was collecting. For a time, his chief interest in collecting was in acquiring a library that would represent the historical landmarks in the development of the physical sciences. But when he realized that his interest in *Alice in Wonderland*—and in her friend the Reverend Charles Dodgson (a.k.a. Lewis Carroll)—was competing with his plans for this library, he faced the inevitable: he had to choose to which of these delights he would dedicate his limited resources. *Alice* won, with the result that at the end of his life, Warren Weaver's Lewis Carroll collection, now at the University of Texas in Austin, was among the important private collections in the world.

Weaver derived great pleasure and satisfaction from his Carroll collection, and some of his enthusiasm found its way into print. Probably the most interesting of these publications is a book called *Alice in Many Tongues.* The book in part reports on the problems and fun of acquiring so many different translations of *Alice.* But it also discusses the problems that must be faced in trying to come to grips—in many different tongues—with the difficulties introduced by a text that relies on parodied verse, puns, nonsense words, jokes involving

[11] Weaver, *Scene of Change*, p. 103.

logic, and twists of meaning for much of its delight. When *Alice in Many Tongues* was written, translations had been made into forty-seven languages; there were over 300 translated editions. The total number of languages represented in the Weaver collection was forty-two (although he had 160 different translations).

The pursuit of *Alice in Wonderland* and other aspects of Dodgson's activities was what Weaver called one of his minor enthusiasms. Religion was a major enthusiasm after his family, which came first, and his work, which came second. From earliest childhood, church was a family ritual, and in adulthood, it had become a cherished part of Sunday's special quality. For years there seemed to be no need to question the interrelationship between science and religion; each played an important role in Weaver's life, but he felt no conflict between them. When he decided in the 1950s that he should examine the conflict many other people did feel, his conclusion was that he could find none between a properly humble science and a properly intelligent religion. He became the scientist par excellence who was often invited to speak at churches and at religious gatherings. Whenever he published an article on this subject, it was widely reprinted. One article, "A Scientist Ponders Faith," was published in the *Saturday Review* of January 3, 1959, and was reprinted by nine other publications during the next two years. Weaver was convinced that there was a permanent core of truth in religion as there is in science and that religious ideas, like scientific ones, evolve with the acquisition of new knowledge. He was perfectly comfortable with his conclusions, realizing full well that they did not conform with the bulk of religious opinion.

CONCLUSION

How to sum up the account of this extraordinary man? Witty, forthright, a superb raconteur, skilled in the use of words as few of us can hope to be, Warren Weaver was a man whose company was a constant source of stimulation to those who were closely associated with him. He was a prodigious worker and a man for whom the conquest of a new and difficult idea, particularly in science, was an event of importance. He viewed science as the most successful of man's intellectual adventures, and in some senses his whole life was devoted to science.

He bore the discomforts of declining health with fortitude, and lived the last of his years with a grace that made them as admirable as the many years before them—years rich in enjoyment and achievement.

IT IS DIFFICULT TO EXPRESS adequately my appreciation of the kindness and hospitality of Warren Weaver's immediate family in helping me to arrive at an adequate understanding of his multifaceted life, some parts of which were quite outside my personal experience of him. Mrs. Weaver put at my disposal his personal records filed at their Connecticut home, including a copy of the oral history interview recorded for the Columbia University Oral History Project in the spring of 1961. In addition, she responded to my questions by calling upon her experience and her own recollections.

The Rockefeller Foundation has been generous with its help and has provided me with access to the Weaver files at the Rockefeller Archive Center at Pocantico Hills, New York. Assistance with this memoir also was generously given by a number of people associated with diverse phases of Warren Weaver's life. These include, in addition to the Weaver family, Dennis Flanagan, H. H. Goldstine, Alexander Hollaender, Robert S. Morison, Gerard Piel, E. R. Piore, Nan S. Robinson, and Dael Wolfle. For all of this help, I express my great appreciation.

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