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DAVID ROCKWELL GODDARD

1908—1985

A Biographical Memoir by

RALPH O. ERICKSON

Biographical Memoir

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David R. Goddard

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BY RALPH O. ERICKSON

DAVID R. GODDARD had an eminent career as a plant physiologist, as an educator, and as a university administrator. His advice was frequently sought in matters of national importance.

FAMILY BACKGROUND AND EARLY EDUCATION

Goddard was able to trace his male ancestry in America back six generations to William Goddard (1628-91), a merchant who left London with his wife and children after they had lost all their possessions in the great fire of 1666 and settled in Watertown, Massachusetts. In England another five generations can be traced. Goddard's mother's family, the Rockwells, also trace their descent from an ancestor who settled in present New York state before the American Revolution. He is related in some way to Robert H. Goddard ("rocket Goddard"), the pioneer investigator of rocket propulsion; to Maurice Goddard, who as a longterm Pennsylvania state official was a leader in environmental matters (Department of Environmental Resources); and to H. H. Goddard, the early and perhaps misguided advocate of the Binet test of intelligence, whom Dave sometimes jokingly referred to as the "feebleminded Goddard."

Goddard was born in 1908 in Carmel, California, the fifth of six children of Pliny E. Goddard. Since Goddard believed his father to have been the strongest influence in his life, something should be said of him. Born in Lewiston, Maine, in 1868, Pliny Goddard attended school in Maine and Poughkeepsie, New York. He earned his B.A. and M.A. degrees at Earlham College. After teaching school in Indiana and Kansas, Pliny married Alice Rockwell, a fellow teacher, and was sent by the Society of Friends as a lay missionary to the Indians of the Hoopa Valley in northern California. There he made a study of the Hupa Indian culture. At the University of California, Berkeley, he earned a Ph.D. degree in 1904 for the now classical work with the Hupa. After five years on the faculty at Berkeley, he was appointed associate curator of ethnology at the American Museum of Natural History in New York City, and the family moved east. He remained at the museum as curator until his death in 1928.

The Goddards lived in Leonia, New Jersey, a pleasant residential town virtually in the shadow of the George Washington Bridge, an easy commute to Manhattan. Goddard attended school there from kindergarten through high school. He has said that the schools were generally excellent but that, except for biology, the science was mediocre, and with his father's advice he postponed chemistry and physics, to begin them at the university level. In early 1922, in his first year of high school, Goddard was seriously ill with what was thought to be influenza and spent a long convalescence at home, sleeping in his father's library rather than the room he shared with his brother. During this time he read widely, T. H. Huxley, Henry Drummond, Havelock Ellis, Dickens and so forth. He then realized that he must prepare for final examinations and studied at home. He returned to school in early June for the final examinations,

which he passed with higher grades than in any previous year. At age fourteen he realized the valuable lesson that one can learn outside the classroom.

When he was fifteen, his father bought a secondhand greenhouse. He, his father, and his brother dismantled it and reassembled it about one-half mile from their home. During his last two years of high school he spent most of his spare time operating the greenhouse and selling nursery stock. He said this experience turned him toward ornamental horticulture and later to botany. He also said that during the period when he and his father operated the greenhouse, his father directed his reading and was often critical of his views and challenged his "facts" and interpretations; he felt that without doubt his father was his best teacher.

UNIVERSITY OF CALIFORNIA, BERKELEY

Goddard chose to go west for his university education. In the company of an anthropologist friend of his father, Gladys A. Reichard, they drove from New Jersey to New Mexico and Arizona over mostly primitive roads, camping along the way. After a brief visit in the desert with his father (his last), he went on by train to Berkeley. This, his first trip across the continent, was an exciting and educational experience. Goddard found Berkeley a "wonderful place for an independent and self-reliant student," where he quickly got to know many faculty members, such as Alfred Kroeber and Robert Lowie, friends of his father in the anthropology department. He has listed faculty members in the botany department whom he got to know outside class: Ernest B. Babcock, Lee Bonar, Roy Clausen, H. H. Dixon, Thomas H. Goodspeed, R. M. Holman, Willis L. Jepson, Herbert L. Mason, Lucille Roush, and William A. Setchell. In his first year Goddard was given a key to the botany building and a

corner where he could keep books, collections, and a microscope. Setchell later became his advisor, mentor, and friend and even gave him access to his private library. Goddard said he probably took too many courses that were primarily descriptive, such as local flora, morphology, and taxonomy. But he had genetics with Babcock and Clausen, chemistry with Joel H. Hildebrand, and cell physiology and biophysics with Sumner Brooks, and he took courses in anthropology, philosophy, and the history of science. As a student with an independent bent, he was admitted to a graduate seminar in his sophomore year.

Goddard's summers were spent in the field: at the end of his first year, with Bonar, as a collector and preparator for the freshman courses; after his second year, as an assistant to Babcock searching for *Crepis* (hawkweed) from the White Mountains of Arizona to the Colorado Rockies and the Grand Tetons; a year later, on a collecting trip in the Sierra foothills with Jepson and in a job with the white pine blister rust program of the U.S. Forest Service. Goddard said that much of his education came in these summer periods.

Goddard went on to graduate work at Berkeley, largely on Setchell's advice. Setchell assured him that "he would see" that Goddard obtained a National Research Council fellowship on getting his Ph.D. degree. He kept up his friendship with the faculty members he had known as an undergraduate and added those of Charles Lipman, a plant physiologist; Paul Kirk in biochemistry; Harold Blum and Sherburne Cook in physiology; Victor Lenzen in physics; and A. J. Salle in microbiology. Though not required, he took such courses as physical chemistry and thermodynamics, biochemistry, advanced bacteriology, and history of science. He continued his independent ways. Told of a graduate seminar course in comparative physiology organized by Blum and Cook, he signed up for the course as a student

and discovered that the course faculty were listed as Blum, Cook, and Goddard.

For his doctoral research Goddard studied the metabolism and nutrition of a dermatophyte fungus, *Trichophyton*. This led to his later interest in protein structure. He stayed on at Berkeley for a year after his degree, as a teaching fellow. During this year he and Fred Uber investigated the X-ray killing of spores of the fungus *Neurospora*. In this research many mutant spores were produced, including some that were nutritionally deficient. Some of these mutants were given to B. O. Dodge and served as markers in his genetic work. It might be said that Uber's and Goddard's work set the stage for the later work of George Beadle and Edward L. Tatum, their one-gene/one-enzyme hypothesis and the 1958 Nobel Prize, which they shared with Lederberg.

ROCKEFELLER INSTITUTE

The following year Goddard was awarded a National Research Council fellowship to work with Leonor Michaelis at the Rockefeller Institute in New York. There he assimilated Michaelis's concept that the oxidation of organic compounds occurs in single electron steps (semiquinones) and later published a landmark paper with James LuValle that laid the foundation for what are now known as free radical reactions in biology.

Michaelis was not interested in the *Neurospora* work that Goddard had done, but he was excited when Goddard showed him that keratin (hair, wool, feathers), which is not normally digested by proteolytic enzymes, could be so digested if the disulfide bonds were first reduced. He and Michaelis showed that the fibrous structure of the protein could be degraded by reduction of the disulfide bonds:

$$2\ H^{+} + R\text{—}S\text{—}S\text{—}R \rightarrow 2\ R\text{—}SH$$

and that such reduction changed the inertness of the fibers to a biologically and chemically reactive form. The structure was partially restored by later spontaneous oxidation. This was one of the earliest transformations of protein structure. Goddard found thioglycolic acid to be a good reducing agent for this purpose. This reagent and other thiol compounds became the basic ingredients of the permanent wave solutions used in quantity in the cosmetics industry. On more than one occasion proposals were made to Goddard that he apply for a patent to protect this application. He rejected all these proposals out of hand, being interested in the scientific implications, not the commercial potential, of the discovery.

Subsequently, he showed that the tripeptide glutathione, which occurs as a dimer with the two units, R—SH, linked by a similar R—S—S—R bonding, is readily reduced under biological conditions by the coenzyme triphosphopyridine nucleotide, TPN. This work will be related below.

ROCHESTER

In 1933, after his two years at the Rockefeller Institute, Goddard was offered a position at the University of Rochester by B. H. Willier, who was then building the Biology Department, a department that was to include a remarkable group of biologists: Curt Stern, James Neal, Herman Rahn, David Perkins, and Ernest Hadorn. All of these men, and Willier as well, became members of the National Academy of Sciences. In addition, George Corner, Wallace Fenn, and George Whipple, at the medical school, became members of the Academy.

At first Goddard was housed at the older campus of the university with very little equipment and little contact with the more active members of the department, but he then

moved to the new River campus. At Berkeley he began studying the metabolism of fungi, which until then had been rather neglected. He picked up the observation of B. O. Dodge that the spores of *Neurospora* are dormant and need brief heating in order to germinate. At Rochester Goddard defined the heating temperature as 49°-52°C and found that they could be thus activated to germinate even if respiration was fully inhibited by cyanide (HCN) provided that the HCN was removed afterwards. The activation was accompanied by a large increase in oxygen consumption. Apart from the intrinsic interest of these results, they seem to have channeled Goddard's interest into the respiration of plant cells. He and Paul Allen studied the respiration of wheat leaves infected with powdery mildew; the infection increased the respiration rate by six times, and this was not due to the fungus but to a change in the oxidation system of the leaf cells. The increased respiration was sensitive to cyanide or azide, thus resembling the respiration of animal and microbial cells. Some of this work was carried out during two summers at the Woods Hole Biological Laboratory.

In a short-lived flier into a quite different field Goddard spent part of the year 1941-42 on a Guggenheim fellowship with Edward Adolph studying water and salt balance for man at the Desert Training Center at Indio, California.

Returning to the heat activation of *Neurospora* spores, he and Paul Smith showed that the dormant spores produce no carbon dioxide, CO_2, anaerobically, but the activated spores do, that is, they ferment. The heat treatment thus activates the enzyme carboxylase. From there he proceeded to study the respiration of plant tissues, first with carrot slices and then with tissues of ash and maple trees, showing that they are cyanide sensitive and probably catalyzed by cytochrome oxidase. Barley seeds behaved similarly. The logical next step was to try to isolate the cytochrome oxi-

dase of plants, which he and Allen H. Brown did with wheat embryos, showing that it is photoreversibly inhibited by carbon monoxide, CO. This was followed by the demonstration of cytochrome C in wheat germ. This proof, in 1944, that the cytochrome oxidase operated with the cytochrome C from plants was a milestone, for with Keilin's earlier studies at Cambridge on the participation of the cytochrome system in the respiration of cells and tissues it served to set up respiration as a major field of plant physiology; it also established Goddard's reputation as leader in this field.

Subsequently, in the 1950s, the work was extended to pathological conditions, including crown gall and some pathogenic fungi. Goddard studied cyanide respiration in fungi and showed that under anaerobic conditions the cytochrome system would operate with glutathione or dehydroascorbic acid as hydrogen acceptor. Two important and widely cited reviews, one a chapter in Höber's *Physical Chemistry of Cells and Tissues*, the other written with LuValle in 1948, served to clarify Goddard's own understanding of the intermediate stages of respiration and to make his name well known in the oxygen consumption of plant tissues. In all this work Goddard's broad biological approach, rather than a narrowly botanical, zoological, or medical one, is evident.

UNIVERSITY OF PENNSYLVANIA

In 1946, with the termination of World War II, Goddard was offered professorships at other universities, and he made the decision to go to the University of Pennsylvania as professor of botany. The Goddards lived in a house in the Morris Arboretum, a former private estate in the Chestnut Hill section of Philadelphia, which had been willed to the university to be administered by the botany department until 1954, when they purchased a house in Chestnut Hill.

The botany department in 1946 was housed in MacFarlane

Hall, an old building that was in miserable shape. It has now been razed. Goddard had negotiated with the university for funds for refurbishment of the building and for equipping laboratories. He immediately activated renovations to the building, revitalized the teaching program, attracted graduate students, and organized an active modern research laboratory. New appointments were made, not only in botany but in microbiology and zoology: Daniel O'Kane in microbiology; Edward C. Cantino, mycology; John Preer, genetics; and myself in developmental biology.

The course in cellular physiology that Goddard taught, and a graduate seminar given by himself and others, attracted many students and often postdoctoral fellows, not only from botany and zoology but from other parts of the university. He took the responsibility for the botany seminar, which became a center of common interest for the university's entire biological and biomedical community. He often brought in a distinguished speaker, who attracted a standing-room-only audience.

At Penn Goddard continued his research interest in cellular respiration. He and Constance Holden isolated cytochrome oxidase from potato tubers showing that it is distinct from the tyrosinase that is very active there and is photoreversibly inhibited by CO. With Richard Darby he demonstrated the activity of cytochrome oxidase in the fungus *Myrothecium*. He wrote two reviews of plant respiration, with Bas Meeuse and Walter Bonner. It was my great good fortune to collaborate with him, M. Ogur, and technicians C. Holden, G. Rosen, and K. Sax in studies that we hoped might bring biochemical and physiological information to bear on problems of growth and development of plants, classically considered largely in the morphological context. These ideas are discussed in a preliminary way in his 1950 article "Metabolism in Relation to Growth." These hopes

were not realized, though Goddard contributed much to a study by Ogur, Rosen, and me of nucleic acids in relation to pollen development in *Lilium* and to the study of nucleic acids and other cellular constituents in relation to growth of the root of *Zea mays*. In the root growth studies, data on respiration of the roots was obtained, which with the growth data would have allowed estimates of the energetic requirement of growth and developmental processes. But this analysis could not be completed without Goddard's participation.

In 1950, after four years in the department, Goddard received a scholarly leave from the university and was awarded a Guggenheim fellowship (his second), which he chose to take at Cambridge University, England. His research at Cambridge resulted in the discovery of the enzyme, glutathione reductase, as mentioned above. His reason for going to the biochemistry department at Cambridge was undoubtedly that it was there that Sir Frederick G. Hopkins's pioneering studies of respiratory metabolism led to the discovery of the tripeptide glutathione. As Goddard tells it, the first seminar in the department after his arrival was by Leslie Mapson on ascorbate synthesis in plants. The role of glutathione was discussed and the fact that no enzymatic mechanism was known for its reduction, even though it is usually found in the reduced state in organisms. In the discussion he suggested that the reason a mechanism had not been found was that a suitable hydrogen donor was not known, and he suggested a candidate. Mapson and he, next morning, began experiments that quickly showed that tri-phospho-pyridine nucleotide (TPN, coenzyme II) served as a hydrogen donor in the reaction of an enzyme they characterized and named glutathione reductase. "There was considerable amusement among the biochemists at Cambridge that an American should have found the missing enzyme in the glutathione system that was considered 'Cambridge property.'"

On his return to Penn Goddard became chairman of the Botany Department. However, he felt that separation of the disciplines of botany, microbiology, and zoology was artificial, as did younger members of the faculty. Largely by his efforts, a Division of Biology was formed in 1954, and he became its director. With retirements of older faculty and some increased funding of the new division, there were opportunities to make new appointments. In addition to those mentioned above, appointments made soon after the division was set up were: Allen Brown, plant physiology; Paul Green, plant development; Sidney Rodenberg, microbiology; William Telfer, animal embryology; Robert MacArthur, ecology; Alan Epstein, animal nutrition; Vince Dethier, animal behavior, and others. The distinguished reputation of Penn biology in those years was in large part due to Goddard's energy and talent for recruitment and administration of the group.

The physical facilities for biology were inadequate and scattered among three separate buildings. The university appropriated money for partial renovation of one of the buildings, the Leidy Laboratory, and Goddard was given a mandate to raise money for a new building. This required a great deal of his time and energy; the new building, now named the Goddard Laboratory, replaced the antiquated quarters of botany and microbiology with modern facilities.

ADMINISTRATOR

One of Goddard's reasons for leaving Rochester was that he felt he was likely to be pressed into administrative work, and he hoped that by going to Pennsylvania he would have more time for research. In fact, it did not work out that way, for in his very first months at Penn, Goddard assumed some of the duties of the chairman of the Botany Department, succeeded Jacob Schramm as chairman of botany in

1952, as said above, and became chairman of the Division of Biology in 1954. He was often called on by the dean of the college, the provost, and the president to make administrative recommendations or to find a new senior faculty member. When the university undertook an exhaustive study of its facilities, organization, and programs, the "Educational Survey," Goddard played an important part in the survey, writing the report on the university faculty. In 1961 President Harnwell asked him to become provost, the senior educational officer of the university, and he accepted. Based in part on the data and reports of the Educational Survey, Goddard wrote the "Integrated Development Plan," adopted by the trustees in 1962. This led to a $93 million fundraising campaign and guided the subsequent growth of the university. Goddard pressed for physical plans that were properly designed for the academic program. But his real charge as provost was to develop the quality of the faculty and the student body, undergraduate, graduate, and in the professional schools. He personally interviewed all candidates for appointment or promotion in rank to assistant professor or higher. Formal appointments were made by the trustees on recommendation of the provost; in Goddard's tenure no such recommendations were ever vetoed. He pressed for upgrading salaries and overcoming gross inequities in salaries. Quoting Eliot Stellar, his successor as provost, "His personal scholarship, his values of independent thought and academic freedom, his dedication to the highest standards of academic excellence, his warm and affectionate spirit, and his sterling qualities of leadership all had a chance to express themselves in one of the greatest nine-year periods the University of Pennsylvania has known. It was the 'right man and the right time.' His decisions and actions were not always popular and sometimes led to animosity, but it was generally agreed that Dave was 'tough but fair.'"

During the turbulent years of the Vietnam war, questions were raised about the ethics of military research on campus, some of which was secret. Recognizing that most of these activities were legitimate, and relying on the principle of academic freedom, Goddard worked out a formula requiring that all technical research be publishable without undue delay and that neither the government nor industry be given the authority to determine who conducted and published the research. This became the policy of the university. (Student unrest during this period led to a six-day sit-in in College Hall to protest the razing of homes for expansion of the University City Science Center. An anecdote, as I recall, relates that each morning on his way to the office Provost Goddard and the students greeted each other cheerily, and when they became concerned about the safekeeping of some money they had collected to support the sit-in they asked Goddard to keep it for them in a safe in his office. Seriously, however, by genuinely responding to the students' concerns, he and his staff helped the students to organize a peaceful demonstration, and to present their demands without dangerous disruption.) Despite urging by many students and faculty that the university should take a stand on the Vietnam issue, the position of the administration was to remain unaligned so as to preserve personal academic freedom.

As provost, Goddard was often asked to address various groups concerned with academic policy, and he expressed the theme of many of these addresses in a talk before the American Philosophical Society in April 1971: "Universities serve society best by being centers of free inquiry, where conclusions are openly arrived at, and where there is a receptivity to new ideas" (*Science* 173:607-10).

Goddard retired as provost at the end of 1970 and became professor of science and public policy, then university

professor in biology emeritus. In 1975 he was elected home secretary of the National Academy of Sciences for a four-year term. This entailed spending a part of each week in Washington. He served also as a member of the Council of the Academy and the Governing Board of the National Research Council, by virtue of his position as home secretary. The position brought him into contact with many prominent scientists and scientific problems of the time, but he did not find the position a challenging one, feeling that the intellectually interesting work went through the Office of the President of the Academy. He returned to the University of Pennsylvania as provost emeritus and professor emeritus.

Most unfortunately, in his last years Goddard was afflicted by Alzheimer's disease, which led to his death on July 9, 1985. He suffered the loss to cancer of his first wife, Doris Martin, in 1951, her illness having cut short their stay in Cambridge; and in 1984 his daughter Alison also died of cancer. He is survived by his second wife, Katharine Evans, and his son Robert.

Throughout his career Goddard also applied his talents to a continuous series of offices, committee assignments, and consultative positions. Thus, he brought his ideals of academic freedom and insistence on intellectual excellence and honesty to a broader community than his own university. He was president of the American Society of Plant Physiologists in 1958; editor-in-chief, then associate editor, of *Plant Physiology* (1953-63); and recipient of the society's Stephen Hales Medal in 1948. He served on the Board of Directors of the American Association for the Advancement of Science (1963-68); was president of the Society of General Physiologists (1948); and was president of the Society for the Study of Growth and Development (1953). He was a member of the editorial committee of the *Annual Review of*

Plant Physiology (1949-54) and a consultant to the Manhattan Engineering District (1943-46). As a biological consultant to Commercial Solvents Corporation (1944-50), he contributed to the development of production methods for penicillin. He served on a variety of other advisory committees, panels, and boards concerned with scientific and educational matters.

In 1962 Goddard authored a report of a White House conference on narcotic and drug abuse, which defined the problem of drug abuse as a social illness rather than a criminal offense. He was a member of a panel of the President's Science Advisory Panel, which issued a report on the use of pesticides in 1963, and also participated in a 1970 report on space biology by the Space Science Board of the National Academy of Sciences.

Over the years Goddard was associated with the National Academy of Sciences in various ways. His work with Leonor Michaelis at the Rockefeller Institute (1933-35) was supported by a National Research Council fellowship. He was elected to the Academy in 1950, though already in 1948 he was made a member of the Advisory Committee of the Academy's Chemical-Biological Coordination Center, representing the Botanical Society of America. He served as a member of the Division of Biology and Agriculture (1952-55), which was succeeded by a Biology Council and in turn was transformed into the American Institute of Biological Societies (AIBS). Among several other Academy tasks, perhaps one of the most important was his membership on the Advisory Committee on Science Exchange with the USSR and Eastern Europe (1960-68; chairman, 1966-68). As stated above, Goddard served as home secretary of the Academy from 1975 to 1979.

I HAVE CONSULTED a manuscript autobiography that Goddard

prepared with Katharine E. Goddard and transcripts of talks at a memorial gathering on October 1, 1985, by Stanley E. Johnson, Sheldon Hackney, Britton Chance, Martin Meyerson, Robert Trescher, and Jack Russell. A memorial resolution was recorded in the minutes of a meeting of the Council of the National Academy of Sciences on August 11, 1985. A biographical memoir of Goddard by Eliot Stellar was published by the American Philosophical Society.

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