Books

Vannevar Bush: Setting the Stage For Half a Century of American Science

Endless Frontier: Vannevar Bush, Engineer of the American Century

G. Pascal Zachary
Free Press (Simon & Schuster), New York, 1997. 518 pp. $32.50 hc ISBN 0-684-82821-9

Reviewed by Jessica Wang

Vannevar Bush was a central figure in the history of American science and technology. As an inventor in the 1920s and 1930s he helped launch the early computer age, and as an administrator in the 1940s and 1950s he participated in the dramatic alteration of science–government relations. Critics may assail Bush's role in building the military–industrial complex and turning the physical sciences into an extension of the armed forces, and boosters may laud Bush for ushering in a golden age of research. But none deny his importance to American science in the 20th century.

In *Endless Frontier: Vannevar Bush, Engineer of the American Century*, G. Pascal Zachary, a senior writer at the *Wall Street Journal*, has provided the first full biography of Bush. Zachary's account conforms roughly to a narrative of rise, decline and rebirth. Until the end of World War II, Bush's life followed a steady trajectory upward. The son of a minister in Chelsea, Massachusetts, Bush rose from relatively modest origins. He became a professor of electrical engineering at MIT in 1919, and he ascended to the MIT vice presidency in 1932. During these years, Bush began to design mechanical calculators, and in 1931 he built his first differential analyzer, a landmark in the history of analog computing.

Bush then turned to politics. He moved to the nation's capital in 1939 to run the Carnegie Institution of Washington, quickly joined the National Advisory Committee for Aeronautics and then climbed to the pinnacle of his influence when he became director of the Office of Scientific Research and Development during World War II. At OSRD, Bush oversaw the development of new military technologies, including radar and the atomic bomb. As a wartime administrator and an aspiring politico, he also played a critical part in forging a new partnership between science and the state. The creation of a Federal apparatus for the support of basic research, predicated upon a compact in which the government provided generous monies with few strings attached in exchange for the unforeseeable applications generated by new knowledge, owes much to Bush's efforts.

After the war, Bush's reputation and influence waned. The era of digital computing passed him by; he held steadfast to his beloved analog machines, in which one could easily see the relationship between the mechanism and the calculations it performed, and opposed the development of digital computers. In the political realm, his characteristic arrogance, a source of his managerial ability in academic life and during his OSRD days, ultimately betrayed him. Bush always insisted that experts knew best, and he believed they should have a strong voice in military and governmental decisionmaking. The exigencies of war and a warm relationship with President Roosevelt had allowed Bush unusual latitude, but in the process of exercising his prerogatives he regularly alienated military leaders. After the war, as he tried to convince a new President to expand the role of civilian scientists and engineers in military affairs, he found himself without sufficient allies to operate in the more open political atmosphere of peacetime.

His vision for postwar research also went awry. Bush favored the creation of a large, well-funded National Science Foundation as the primary supporter of basic research. Although he believed the OSRD exemplified the best in science–military cooperation, he opposed its postwar continuation because he felt the military should sponsor basic research only during wartime. But proposals for the NSF went down to repeated legislative defeats. By the time the NSF was finally established in 1950, the military had become the largest sponsor of basic research in the physical sciences. In the meantime, Bush had suffered a near nervous breakdown and lost his political status. As Zachary notes, "By the early 1950s, Bush's conversion from insider to outsider was complete."

Toward the end of his life, however, Bush became a celebrated symbol in computing and science policy. In the mid-1960s, some computer designers pointed to Bush's notion of the memex, a device (never built) that could serve as an aid to human memory and thought by retrieving data stored on microfilm, as their inspiration for the advent of personal computing and hypertext. By the early 1970s, in an era of tightening research budgets, scientists referred to *Science—the Endless Frontier*, Bush's 1945 manifesto on the need for government funding of basic research, with steadily growing reverence. Prominent scientists suggested that Americans owed the science-based economic prosperity of the postwar period to Bush's wisdom and his insistence that the Federal government provide generous support for science. "Bush's ideal of no-strings funding," Zachary observes, "became the mythic prime directive for scientific leaders." Thus, by the time of his death in 1974, Bush had achieved near legendary status.

Endless Frontier provides a good introduction to 20th-century American science and technology for a popular audience, as well as an engaging study of an important historical figure. Zachary's discussion of the building of the Bush mythos is especially original and significant. A few instances of injudicious writing and some loose threads in the analysis occasionally undermine the book's strengths. For example, in 1943, Bush wrote to Herbert Hoover that the US would require military strength and an interventionist foreign policy for the next thousand years if civilization were to survive. Bush's international outlook may have been overly grim, but it seems excessive to suggest, as the author does, that his observations "bore an eerie similarity to Nazi notions of a 'thousand-year Reich.' "

Zachary also fails to explore fully some of the conundrums raised by Bush's life, such as the contradiction between Bush's early populist sentiments and his later disdain for popular opinion and his opposition to govern-

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ment-sponsored antimonopoly policies despite his heartfelt aversion to corporate monopolies and his faith in small inventors. On the other hand, Zachary's decision not to address these and other issues at greater length was arguably a legitimate one: Had he done so, he would have produced a much longer book for a much narrower readership of academic specialists.

As the book's subtitle indicates, Zachary believes Bush epitomized the growing stature of the engineer in 20th-century America. His own narrative, however, opens the possibility that Bush was less a modern engineer than an old-style inventor and tinkerer. Throughout his life, Bush constantly designed new gadgets and machines, both workable and unworkable. Profit was not his motive; once he had achieved economic security in the 1920s, after new radio tubes and other devices earned him valuable shares in Raytheon and Spencer Thermostat, he no longer patented his inventions (including the differential analyzer), because he wanted the world to benefit freely from them. Rather, his psyche demanded that he create, and he produced a dizzying array of devices in his home workshop. The offspring of his fertile imagination included a spring-loaded birdfeeder that dumped off heavy pigeons while allowing his favorite songbirds to feed; a new type of fuel-efficient car engine that the technologically stagnant American auto industry of the 1960s refused to test; and heart valves that were ultimately unusable because Bush possessed too little medical knowledge. From Zachary's account, Bush appears not to have worked from theory; he was a gadgeteer who operated from a purely mechanical sensibility. Is it any wonder, then, that he proved incapable of embracing the digital age?

Master of Modern Physics: The Scientific Contributions of H. A. Kramers

Dirk ter Haar
Princeton U. P., Princeton, N.J. 1998. 288 pp. $39.50 hc
ISBN 0-691-02141-4

Hendrik A. Kramers stood at the center of physics in the first half of the 20th century. A 1987 biography by Max Dresden deals with his life and work and includes an in-depth discussion of early work on dispersion theory and his contributions to quantum electrodynamics. As a substantial part of the oeuvre could not be included there, this new book—*Master of Modern Physics* by Dirk ter Haar—is a welcome addition.

Ter Haar, who studied with Kramers, has a unique approach to scientific biography: He makes us read the original papers; the second part of his book consists of 12 of them, in English, while the first part contains a discussion of the published work and an elucidation of these papers. This format makes the more difficult of Kramers's articles easier to follow. Particularly helpful are ter Haar's comments regarding the pioneering extensions of the old quantum theory, culminating in the Kramers–Heisenberg paper on dispersion and in the Kramers–Kronig relations.

For the important 1923 paper (Phil. Mag. *46*, 836) on absorption and dispersion of x rays, ter Haar has no room, to his expressed regret. He does give the translation of a 1925 paper on Werner Heisenberg's matrix mechanics, to show both how closely it relates to the Kramers–Heisenberg paper and how much they differ conceptually: From a theory of which the results can be expressed in terms of observables, Heisenberg created a theory that deals exclusively with these observables.

Kramers's research on statistical mechanics and on the quantum theory and its applications to solids forms a substantial part of this book. I enjoyed the introduction to "Brownian motion in a field of force" with quotes from Nicolaas van Kampen's analysis. It reads like a detective story, a genre that Kramers treasured for relaxation. (I once heard him converse for a full hour about Erskine Childers's novel *The Riddle of the Sands*).

The theory of flow of polymers, which Kramers began as a consultant at Shell, is reviewed next. The book discusses several papers on equilibrium statistical mechanics, including "Statistics of a Two-Dimensional Ferromagnet," written in collaboration with Gregory Wannier. This paper teaches us much about the Ising model, including the value of the transition temperature—if it exists—but the abstract ends with the statement "the information thus gathered by rigorous methods remains incomplete." When Lars Onsager later solved the problem, Kramers was impressed by the difficulty of the proof, undoubtedly because abstract algebra, which Onsager employed, was not a tool Kramers readily used. When Kramers's student Raymond Houtappel suggested a generalization to hexagonal lattices as a thesis project, Kramers tried in vain to dissuade him, because "it was too difficult." It pleased him, though, that Houtappel succeeded without using abstract algebra.

Of the papers on quantum theory of solids, the best known contains the so-called Kramers degeneracy. Ter Haar discusses the proof, but it is hard to improve on Kramers's simple and lucid derivation unless one prefers Eugene Wigner's proof based on space inversion and time reversal symmetry. I was pleased that ter Haar included the paper on the eigenvalue problem in a one-dimensional periodic potential, which forms the basis of the thesis of one of my students. It excels in elegance and generality and, ter Haar tells us, was "one of Kramers' own favorites."

A prime example of Kramers's inimitable style is found in the derivation of formulas equivalent to the Dirac equation. This is reprinted as paper F and can also be found in Kramers's book *Quantum Mechanics* (translated by ter Haar, North-Holland, 1957). Ter Haar also discusses a contribution Kramers made to Heisenberg's S-matrix theory. It consists of a single but important remark: that the S-matrix should be extended to imaginary values of its argument and that its poles in the complex plane correspond to the bound states of the "scattered" particles. Kramers said this during a lecture that Heisenberg gave during a wartime visit to Leiden. Kramers could not reveal at that time that this discovery was made by his student, Siegfried A. Wouthuysen, who, being Jewish, was in hiding. A footnote in Heisenberg's third paper on the subject, put in at Kramers's request, rectified the omission.

No book on Kramers is complete without mentioning his work on quantum electrodynamics. Ter Haar devotes chapter 4 to this subject, giving a good characterization and adding a few interesting points. On this and the other subjects on which he touches, he has written a stimulating book that brings Kramers's history-making work more into focus, even for those, I among them, who were his students.

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Cats' Paws and Catapults: Mechanical Worlds of Nature and People

Steven Vogel
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Steven Vogel is in the department of zoology at Duke University. He is a biologist who has thought about biomechanics for 40 years. His emphasis, and that of his colleagues, is on engineering practice rather than physi-