tute of Technology from 1921 to 1946 helped to bring science to new prominence in the public consciousness and strengthened the institutions that propelled America's rise to scientific maturity. Despite these important contributions, Millikan has not been the subject of a scientific biography, perhaps because his *Autobiography*, published three years before his death in 1953, has supplied most scholarly needs.

Robert Kargon has not attempted to replace the *Autobiography* as his title might suggest. The portrait he paints attempts to capture not the essence of an individual's life but general traits in the history of American science. He suggests that Millikan's career is "a microcosm of the new roles assumed by the scientist during the course of the century." His sketches of Millikan's activity "as teacher, as researcher, as administrator and fund raiser, as consultant, and finally as celebrity and sage" therefore provide an opportunity to examine how a variety of changes in American science have occurred.

In limning the general, the artist sometimes loses sight of his subject. Millikan's scientific education at Oberlin and Columbia is lost against Kargon's *tour d'horizon* of American graduate education in physics, in which Henry Rowland's department at Johns Hopkins is highlighted, although Millikan never studied there. The penchant for rigorous experimental research and precision measurement that Kargon identifies as an important characteristic of American physics in this period was embodied in the work of Ogden Rood, Millikan's principal mentor at Columbia, as well as in that of Rowland and Albert Michelson, whom Kargon prefers to use as illustrations despite their smaller roles in Millikan's training. Millikan's career as an administrator and fund-raiser at the California Institute of Technology is similarly overshadowed by the activities of George Ellery Hale, his patron at Pasadena. Contemporary research in the history of science has uncovered a good deal about Millikan's scientific personality that Kargon does not incorporate in his portrait, with the effect of blurring the image.

The depiction of Millikan's scientific work found here is effected with broad strokes and ideological tints. Millikan's Nobel Prize-winning measurements of the charge of the electron and his test of the Einstein photoelectric equation are construed as evidence of his "convergent" thinking and of his desire to emulate Michelson. A "conservative in a revolutionary world," Kargon's Millikan wished to become Michelson's "physicist of the sixth decimal place" and so dedicated himself to refining and extending existing experimental measurements in the style of the master of light, and undertook to falsify the photoelectric equation "to restrain the excesses of modernity." Recent studies of Millikan's use of his data in his dispute with Felix Ehrenhaft over fractional electronic charges, which suggest how far Millikan was prepared to go in his conservatism, are not used as they might be to support this analysis. It is, however, difficult to reconcile the analysis with the account of Millikan's cosmic ray work appearing elsewhere in the portrait. Millikan's claim that cosmic rays were the "birth cries of atoms" in interstellar space is a remarkable example of divergent thought in 20th-century science. Kargon's argument that Millikan's deep interest in radioactivity and artificial transmutation of elements and his "fundamental spiritual yearnings" all find expression in this bizarre hypothesis rests on circumstantial evidence. He overlooks the link between Millikan's fund-raising activities and his promotion of this sensational hypothesis, which I have demonstrated elsewhere. The favorable publicity Millikan received convinced his philanthropic patrons that their extraordinary investment in his work was paying dividends and made it difficult for him to withdraw gracefully when Compton and others proved that his underlying assumption of the photonic character of the cosmic rays was wrong. Millikan's later promotion of high-voltage radiotherapy for cancer is another example that Kargon's portrait omits of the kind of scientific entrepreneurship in which his speculations led him to error.

Although Kargon's attempt to find the general in the particular may not have succeeded, his composition, drawn from a rich store of manuscript materials at the California Institute of Technology and elsewhere, is a useful corrective to Millikan's self-portrait that reveals some of the blemishes, as well as the embellishments, of an important life in American science.

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Radar in the United States

New Eye for the Navy. The Origin of Radar at the Naval Research Laboratory. DAVID KITE ALLISON. Naval Research Laboratory, Washington, D.C., 1981 (available from the Superintendent of Documents, Washington, D.C.). xii, 228 pp., illus. $13. NRL Report 8466.

Allison writes of the history of the Naval Research Laboratory from the initial planning before World War I through its formation in 1923 until the early 1940's. This is institutional history of an interesting sort, with radar development used to order and illuminate the history of the institution. Since the Radio and Sound Division was the largest at NRL throughout the period considered, it is logical and fruitful to let a radio topic serve as focus for the study.

Allison has justifiably chosen World War I and World War II as dividing points in the history of radio research in the Navy. World War I spurred the development of the reliable and inexpensive power vacuum tube; Navy sonar research brought forth piezoelectric quartz crystal radio circuit devices, particularly from the work of W. G. Cady at Wesleyan and G. W. Pierce at Harvard. These developments revolutionized radio. World War I also brought dozens of scientists, such as the future Nobel laureate E. V. Appleton, into the field of radio in the first place. Similarly, World War II brought on microwave high-power tubes (including the klystron, and especially the British cavity magnetron) and the social science invention of "operations research." These latter developments in fact were the major two contributions to the success of radar in World War II, since radar is not merely a scientific instrument but a technological matrix of devices and methods.

Perhaps the most interesting portions of the book are the earlier ones, where actions are seen on a smaller scale and discussed in more detail. By necessity the focus widens in the years just before 1940 from the individual toward the "mission" or "project" and the ubiquitous acronyms of military technology (XAT, CXAM, CXAM-1, and so on). Though he does not make a major point of it, Allison's account reveals factors that affect morale and productivity in an institution. These include continuity in leadership such as was provided by A. Hoyt Taylor and the drifting in purpose as the NRL was shuffled around from one Bureau or Command to another in the Navy. The intraservice struggles, arguments over research versus product engineering, and tension between scientists and bureaucrats will seem familiar to those versed in the history of military and civilian government laboratories.

The issue of independent discovery is mentioned several times but not really treated. For example, we learn of the radio-frequency duplexer invented by Robert M. Page and the "squegger" oscillator "originated" by Page. It was rather widely known in radio circles that the duplexer, the squegger oscillator utilized to produce pulses in radio-frequency amplifiers, and various cathode-ray tube display techniques were simultaneously or previously in use by E. V. Appleton and by R. A. Watson Watt and others in England. Allison nicely discusses an issue of Allied compromise about 1940–41, in the choice of instrumental techniques regarding the adoption of the U.S. or the British "IFF" radar recognition system for ships and planes. Technological compromise for operational and political reasons is an important fact of life in modern technology.

Allison disagrees with Henry Guerlac and others who see radar at NRL as growing out of earlier ionospheric radio research, but he does not convince in spite of quotations he utilizes. The essential point is that if Taylor, Leo Young, E. O. Hulburt, Ross Gunn, and others at NRL had not thought, experimented, and written about radio engineering and ionospheric physics during the 1920's the NRL would not have been in a position to develop their prototypes of high-frequency and very-high-frequency radar in the 1930's. A similar situation is represented by the early solar physics and geophysics rocket research begun at NRL about 1946 by H. Friedman, R. Tousey, F. S. Johnson, J. A. Jackson, and others. This preparatory work not only achieved valuable results, it produced what would be the primary core of scientific personnel for space science when NASA was formed in 1958.

It would have been profitable had Allison included more comparative history. For example, competition between NRL and private industry over the design and construction of radio equipment in the early 1930's roughly parallels competition at the same time between the National Bureau of Standards and the Carnegie Institution of Washington over intellectual superiority, geographical territory, and instrumental standards in ionospheric radio research. And we can find other comparisons: 35 years after the founding of NRL we see NASA similarly born with funding, yet with goals to be formulated later. Allison concludes his work with a nice overview that might well be read as an introduction.

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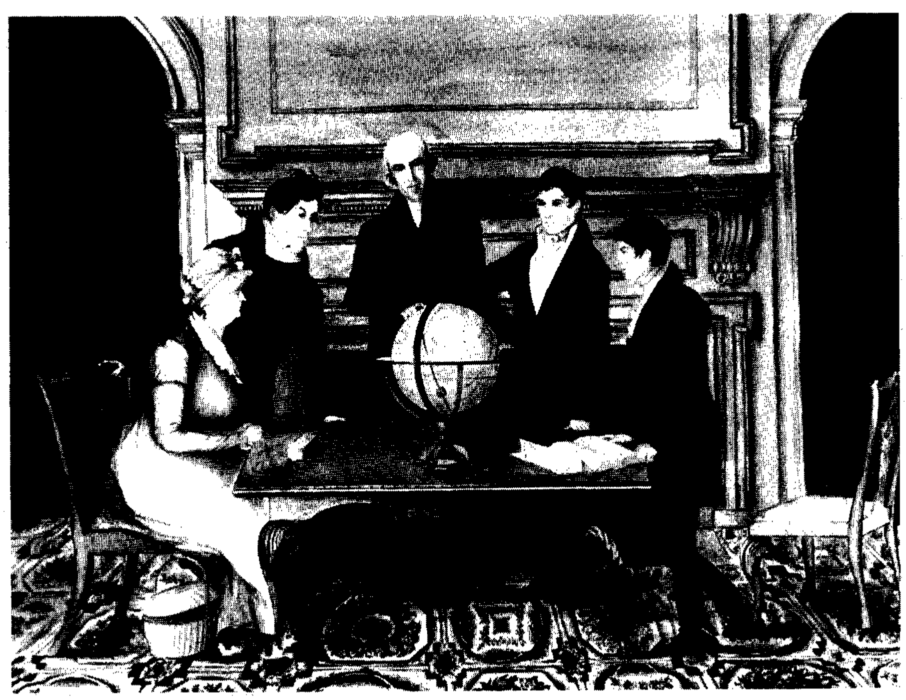
Two American Inventions

Emulation and Invention. BROOKE HINDLE. New York University Press, New York, 1981 (distributor, Columbia University Press, New York). xx, 162 pp., illus., $22.50. Anson G. Phelps Lectureship Series on Early American History.

This book might also have been titled "Spatial Thinking and Invention," for its major theme is as much, or more, the role of nonverbal, spatial, or visual thought in the inventive process as the role of the emulation motive. Brooke Hindle is senior historian at the National Museum of American History (Smithsonian) and one of the major contributors to the history of American technology. Here he examines the process by which two prominent American inventions—the steamboat and the telegraph—were conceived and developed. Hindle points out that the men who brought these innovations to fruition, Robert Fulton and Samuel F. B. Morse, were both originally aspiring artists, both went to London to paint under (and to emulate) Benjamin West, and both clearly were able to design a complex mechanical system by the employment of spatial thinking. And, as he shows, many others in the community of mechanicians who contributed to these new developments had formal training in the graphic arts. The point is further emphasized by a series of well-chosen illustrations from the inventors' own pens.

The book is a substantial contribution to the literature on nonverbal thinking by historians of technology. This subject has been relatively neglected by psychologists in favor of the study of language processes in cognition, although, as Hindle points out, the interest in differences in right and left brain function does include a concern with nonverbal processes. Note might also have been made of the work of Roger Shepard (Stanford) on mental images and the role of visual imagery in scientific creativity. Hindle's case studies make one wonder again at the social process by which thought has come to be regarded as isomorphic with



Watercolor of the Samuel F. B. Morse family, circa 1810. "The extensive visual imagery associated with . . . Morse offers a fine opportunity to move through his art career and through his telegraph career as well, by way of images. Already in his day the record of a leading artist who played a major role in developing a science-based technology had to be explained. The one approach that ties together these two apparently diverse careers, other than bare coincidence, is the perception of that mental manipulation of images that lay at the center of each effort." [National Museum of American History; reproduced in *Emulation and Invention*]