The Process of Innovation

Syntony and Spark. The Origins of Radio. HUGH G. J. AITKEN. Wiley-Interscience, New York, 1976. xviii, 348 pp., illus. $15.95. Science, Culture, and Society.

Aitken's history of radiotelegraphy from Hertz to Marconi has a deeper purpose: to explore the nature of creativity within and in the relations between the scientific, technological, and economic sectors of society. The exploration is carried out with the use of a vocabulary both literal and metaphorical. In Aitken's usage, "spark" refers to Heinrich Hertz's use of spark gap equipment in tests of Maxwell's equations; metaphorically, it refers to creative insight. "Syntony" is technically synonymous with tuning or resonance, Oliver Lodge's crucial discovery that allowed Hertz's spark to be used for communications by Guglielmo Marconi; metaphorically, the term characterizes the combination of circumstances in the respective sectors that makes it possible for transfer of innovation to occur between them.

Prefaced by a chapter on syntony, Aitken's history consists of biographical sketches of Hertz, Lodge, and Marconi, who represent the semiautonomous spheres of science, technology, and economic activity respectively. Aitken argues that Hertz's spark did not lead to Marconi's radiotelegraphy in an automatic or mechanical way; rather, a full process of innovation requires creativity in each relevant sector as well as persons or institutions to "translate" the creative insights into syntony. In an epilogue, Aitken further tunes his theory with his history.

Following the work of Robert Merton and Thomas Kuhn, Aitken presents Hertz as a pure scientist working according to the Maxwell paradigm. Maxwell's model of electromagnetic fields hypothesized that any acceleration of electrical charges (like a spark) produced waves moving through empty space at the finite velocity of light. Using an acoustical analogy (tuning forks), Hertz tested this hypothesis by developing roughly tuned apparatus that allowed him to detect and measure the frequency and wavelength (the multiple equaling velocity) of spark oscillations. His oscillator, an induction coil connected to a dipole antenna, transmitted waves to a loop receiving antenna. Finding the velocity of the waves to be finite and on the order of magnitude of that of light, he published this empirical verification of Maxwell's paradigm in July 1888. Hertz, whose work was in the realm of pure science, ignored the possible use of his apparatus for communications.

In August 1888, Lodge, working on the practical problem of lightning rods in terms of inductive reactance, presented findings whose "theoretical implications were identical" (p. 82) to those of Hertz's work on wave velocity. Aitken presents Lodge as both a technologist and a scientist: Lodge's practical work on lightning (a spark) converged with his scientific interest in verifying Maxwell's theories. Adopting Hertz's apparatus, Lodge discovered that inductive and capacitive reactance varied with frequency in opposite ways; at the proper frequency, their effects neutralized each other and thus created a "syntonic" (tuned) circuit. Lodge also improved detection with the Lodge-Branly coherer. In 1894, he demonstrated a working technological system of wireless signaling before scientific audiences. Lodge thus invented radiotelegraphy, but he lacked entrepreneurial vision: he did not patent syntonic circuitry until 1897 and did not begin manufacturing commercial apparatus until 1901.

In 1894, an obituary of Hertz by Augusto Righi sparked the imagination of one of Righi's students, Marconi. A psychologically based "technological obsession" (p. 191) with distance, along with economic goals, distinguished Marconi's motives from those of pure or pragmatic science. Encouraged by powerful patrons in the British government, Marconi demonstrated his wireless system in 1896. Analyzing his system patent of 1897, Aitken describes Marconi's overall style as "determined empiricism" (p. 192) that led to "critical revision" (p. 187) of other's insights. To increase his ship-to-ship and ship-to-shore market, Marconi made longer-distance communication possible by enlarging both antennas and oscillator sparks. To reduce interference, he developed an improved version, which he patented, of Lodge's syntony apparatus. Marconi overcame the technical problems involved in simultaneously achieving distance and tuning selectivity in his disk discharger invention of 1907; thus, "Syntony and spark had finally been reconciled" (p. 282). Obtaining Lodge's basic syntony patent in 1911 and winning subsequent patent suits, Marconi's company held the dominant position in the industry by 1914. Marconi's critical empiricism bridged the technological and economic sectors; it also produced anomalies for science.

In his epilogue Aitken develops his theory of innovation by means of three "successive approximations." The first approximation is the mechanical model, which assumes an automatic, unidirectional flow of information from science to other spheres of activity. Aitken finds this model biased toward "supply" inputs: relations are more complex and reciprocal than it allows. From his history he concludes:

> Neither the content nor the timing of technological advances are uniquely determined by prior changes in the supply of new knowledge by science. . . . The transfers of new information that take place between science and technology are determined as much by the demand function of technology as by the supply function of science [p. 311].

The same is true of technology-economy relations.

In his second approximation, Aitken envisions the information flow as occurring in two "markets," or fields of interaction, science-technology and technology-economy, and argues for "feedback loops," or reverse flows, in each market. In the second market, technology provides the economy with a forward flow of devices; but the economy screens this flow by feeding back cost and demand functions. Similarly, technology screens scientific inputs in the first market by feeding back information and special-purpose devices. Aitken is especially impressed by the feedback of anomalies. He argues, however, that the two markets are structured differently: the scientific sector responds mainly to internal signals and is thus more "self-steering" than the other sectors; usually, technology pulls information out of science. Nevertheless, the feedback loops in each market lead Aitken to assert that the rate and direction of change in the three sectors are not autonomous: "The three systems do not track independently over historic time" (p. 327).

In his third approximation, Aitken views the three sectors as subcultures, each having its own language and norms. Forward and reverse flows are not automatic but depend on a particular social role that Aitken terms the "translator" function. Persons and institutions performing this highly creative role must function in more than one subculture. In the development of radio, Hertz, Lodge, and Marconi were translators between pure science and industry:

> At each stage in the process of translation, information generated in one system was converted into a form that "made sense" in terms of another; and at each stage new information was blended with what was already known to create something essentially new [p. 335].

The fact that Aitken does not explicitly take the next step in his argument may relate to his selection of sources for both his history and his theory. In Aitken's view, general ideas or metaphors make these new conversions or blends possible by "serving always to organize or give meaning to information that would otherwise remain disjunct and without structure" (p. 44). In his history, the idea of syntony organized the perceptions of the three translators. Perhaps Aitken could show that intellectual influence on the translators by presenting evidence from their personal papers. But his history rests largely on information from professional journals, government records, and biographies. He uses these sources with care and intelligence. In reassigning priority of invention to Lodge (p. 123), for instance, he constructs a plausible argument based on a wide range of materials. But an attempt to explore the conditions of creativity that makes no use of primary sources, such as personal papers, cannot be wholly satisfactory or convincing.

Nor does Aitken show a broad acquaintance with current literature pertinent to his work. The writings of such historians of science as Arnold Thackray, Paul Forman, and Barry Barnes suggest that science was not as autonomous as Aitken portrays it as being. Barnes's work on the role of metaphor in science would seem particularly useful for Aitken's purposes. Aitken reveals more familiarity with current work in the history of technology but neglects Thomas Hughes's work on technological systems and on the relations between science and technology and Elting Morison's sociopsychological interpretation of creative invention. In economics, the work of the post-Schmookler "technological change" school (of, for example, Richard Nelson, W. Paul Strassmann, Edwin Mansfield, or Raymond Vernon), which explores relations between technology and economics, is ignored. In addition, Aitken misses a number of works from the Tavistock Institute (of, for example, Howard V. Perlmutter or Eric Trist) that treat economics as a system of social action. Aitken is a translator, though, and translators are never as specialized as the enterprises they bridge.

Aitken's exploration of the creative relations between science, technology, and economic activity, which is his fundamental concern, is a valuable contribution. His theory points to the importance of technological anomalies for scientific paradigms, alerts us to the creative nature of both technological and economic activity, identifies a translator role, and, most important, suggests an effective way of thinking about the full creative process of innovation. Aitken's analytical isolation of the translator role in that process and his suggestion that a translator's perception of relevant information is as important to the process as the information or knowledge itself clearly carry too many historical and current implications to explore in a review. His book is bound to spark much thought and discussion.

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Improving Plant Yield

CO_2 Metabolism and Plant Productivity. Proceedings of a symposium, Madison, Wis., June 1975. R. H. BURRIS and C. C. BLACK, Eds. University Park Press, Baltimore, 1976. xiv, 432 pp., illus. $39.50.

The fifth Steenbock symposium provided an opportunity for many of the world's leading researchers studying CO_2 metabolism in plants to assess the limitations of photosynthetic productivity in terrestrial plants and to propose researchable methods of increasing such productivity. The 26 symposium papers included in this volume address all major aspects of CO_2 metabolism in plants. The papers are authoritative and well conceived. Some are straightforward summaries of research in progress, and others describe one or two decades of effort by individual laboratories to improve crop yield by using conventional plant breeding approaches to increase the photosynthetic capacity of plants.

Wallace and colleagues have analyzed dry bean genotypes that differ in CO_2 assimilation rate and have concluded that the polygenic regulation of the process makes breeding for CO_2 assimilation rate practically ineffective. Zelitch has come to the same conclusion working with tobacco. Ogren and Moss have screened thousands of seedlings of agronomic plant species that have been treated with conventional mutagens without discovering a single mutant that was useful in a breeding program for photosynthesis.

These perplexing results have spawned other innovative research. Bjorkman has attempted to cross related plant species that have different CO_2 assimilation pathways. Zelitch has used tissue culture techniques in an attempt to generate phenotypes that have more efficient photosynthesis and altered daylight respiration. Ogren is attempting to regulate CO_2 assimilation and daylight respiration by chemical and genetic modifications of the primary enzyme in the pentose phosphate cycle.

As the efforts to discover new genetic or chemical tools to modify the rate of photosynthetic CO_2 fixation continue, several physiologists are questioning the extent to which the rate of CO_2 assimilation limits a plant's productivity in the fields. Loomis and colleagues and Wallace and colleagues correctly argue that, regardless of photosynthetic capacity, it is the utilization of the photosynthate by the crop in such processes as leaf expansion, fruit growth, nitrogen fixation, and respiration that ultimately determines yield. Moss shows how the capricious environment may prevent the realization of the genetic potential for photosynthetic CO_2 assimilation in current crop genotypes.

The volume offers a balanced presentation of the status quo and a lucid discussion of the challenges confronting researchers studying photosynthetic CO_2 metabolism. The hypotheses framed by the contributors will undoubtedly tempt new, bright minds to take up the challenge of increasing the photosynthetic productivity of crops.

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Scattering Phenomena

Optics of the Atmosphere. Scattering by Molecules and Particles. EARL J. MCCARTNEY. Wiley, New York, 1976. xviii, 408 pp., illus. $24.95.

Not long ago optics meant to most people the physical properties of visible light, radiation that we could see. During World War II the military developed infrared night vision devices, and, more recently, vidicons have been developed that can sense ultraviolet radiation and present an image of it on a television screen. So optics nowadays encompasses the entire spectrum of electromagnetic radiation, from the extreme ultraviolet to the far infrared. With the development of optical sensors, new fields of environmental research, called remote sensing or optical probing, have sprung up. Optical sensors enable us to detect and monitor pollutants in the atmo-