Technology in the Seamless Web: "Success" and "Failure" in the History of the Electron Microscope

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The microscope, rivaled only perhaps by a white lab coat, has assumed a status as *the* symbol of science in the modern world. The mere image of a generic microscope conjures up mental pictures of a scientist hard at work in a laboratory uncovering the mysteries of the universe. Indeed, increasing the power of the microscope has, by implication, been tantamount to increasing the power and knowledge of scientists. In this scenario, the most powerful microscope, the state-of-the-art electron microscope, unlocks nature's secrets by enabling scientists to view erstwhile hidden parts of the universe through magnification levels on the order of 200,000 times an object's actual size. Such microscopes, it could be argued, are the leading tools with which scientists push forward the frontiers of knowledge and reveal the secrets of the molecular world. In such a view, the objective scientist is empowered by his or her instrument, which has been technically determined by factors quite distant and distinct from social forces with which, say, an office manager or a teacher has to contend.

Yet the history of the electron microscope, particularly its commercial development, reveals quite a different and more complex story—one that supports the idea that, while technology obviously has an impact on society, social factors, in their turn, have as forceful an impact on technology. In examining the early history of commercial development of the electron microscope at RCA and General Electric (GE), one can glean general insights into the relationship between social forces and the pathways of technological development.[1]

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[1]For other insights into the role of social factors in the development of technological artifacts, see David Noble, "Social Choice and Machine Design: The Case of Automatically Controlled Machine Tools," in *Case Studies on the Labor Process,* ed. A. Zimbalist (New York,

0040-165X/95/3601-0001$01.00

Early in the development of the electron microscope, a question arose concerning two different types of lens systems. It was not at all obvious whether the *electromagnetic* lens, on the one hand, or an *electrostatic* design, on the other, would prove to be superior. Buried within this choice between two technologies are lessons in how technology and science function within the larger contexts of industry, communities of practitioners, and society at large. The question of technological choice[2] is instructively revealed on examining the development of the electromagnetic and electrostatic electron microscopes in the international arena. Such a comparative analysis is suggestive of those factors that are most significant in shaping the course of technological development. Further, the efforts of two American firms, RCA and GE, to develop and market an instrument provide an interesting look at the relationship between instrument makers and the research community.

In the United States during the 1940s and 1950s, GE made two unsuccessful attempts to market electron microscopes with electrostatic lenses. In the same period, RCA achieved success in producing and selling electron microscopes with electromagnetic lenses. It has generally been accepted by scientists involved in electron microscopy that GE's lack of success was due to the inherent technical inferiority of the electrostatic lens.[3] A closer examination of the electron microscope, however, including developments in the international setting—notably in Germany and Japan—suggests that this assumed technical inferiority was not necessarily the cause for its commercial failure. Contemporary

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1979); and Ruth Schwartz Cowan's discussion of the refrigerator in *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave* (New York, 1983), pp. 127–50.

[2]The word "selection" could just as easily be employed here in the sense that George Basalla uses the term in his evolutionary model of technological development. Basalla argues that decisions regarding the path of technology are somewhat arbitrary, based on social as well as technical factors. I have used the word "choice," however, in order to employ the connotations of social factors inherent in that term. See George Basalla, *The Evolution of Technology* (New York, 1988), chap. 7, "Selection: Social and Cultural," esp. pp. 189–90.

[3]Representative of the predominating retrospective view is that offered by V. E. Cosslett, "50 Years of the Electron Microscope," *Advances in Optical and Electron Microscopy* 10 (1987): 224–26. In this account, Cosslett speaks of the magnetic electron microscope having "won the competition" based on its technical superiority. When we compare this 1987 assessment with Cosslett's more contemporaneous observation of 1951, however, the results of the "competition" are less preordained. In his earlier work, *Practical Electron Microscopy* (London, 1951), he speaks of the advantages of the electrostatic system without dismissing it as a possibility for the future of electron microscopy, noting its potential for "production as a compact, cheaper instrument of limited range of performance for routine work." See pp. 25–27 and esp. 271–74.

evaluations of lens systems conducted by firms in other countries, as well as successes in marketing electrostatic microscopes abroad, indicate that much more was involved in the successes and failures of particular electron microscopes made by RCA and GE.[4]

Thus, an examination that includes a comparative perspective supports the contention that the success of the electromagnetic microscope was not due to its technological superiority. A look at this machine's early history also reveals the sort of effects that institutional structures and approaches can have on the development of technology.

Because of the electron microscope's special position in advancing the frontiers of science, its development may have ramifications not only for technology but also for the subsequent path of science as well. For instance, the dynamics of technological development in this case also provide insights into the development of scientific disciplines closely related to, if not wholly contingent on, advances in electron microscopy—such as materials science, microanalysis, and a host of biological sciences concerned with the submicroscopic world.[5] Inasmuch as these fields of study are dependent on a technical instrument for their advance and indeed their very existence, the history of the device that

[4]Wiebe Bijker, Thomas Hughes, and Trevor Pinch et al. argue for an evaluation of technology that considers it as developing and functioning in, as well as acting on, such a societal context, or "web." When viewing technology from such a vantage point, we see that various social factors impinge on technical development, and we must thereby dismiss our erroneous assumption of a "linear structure of technical development." Instead of technology progressing in a straight-ahead fashion according to what is technically possible, it proceeds along socially determined paths characterized by an "interpretive flexibility." In this model, more than one possibility exists regarding what is accepted as valid, and this validity is continually subject to social influence as it gains "rigidity" through social mechanisms and finally reaches "closure" in its acceptance in the social-cultural milieu. Thus, what is deemed a "success" is only such because it has, for some reason or combination of reasons, found acceptance in the contextual web. Conversely, what is considered a technological "failure" in retrospect must be seen not necessarily for its intrinsic technical deficiencies but, rather, for the particular impediments it has met in the larger contextual setting. We can, and must, therefore, view the history of technology "symmetrically"—that is, taking into account and examining the so-called failures as carefully as the successes in order to garner the fullest insights into the processes of technological development. See Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems* (Cambridge, Mass., 1987), passim; and also Thomas P. Hughes, "The Seamless Web: Technology, Science, Etcetera, Etcetera," *Social Studies of Science* 16 (1986): 281–92.

[5]The electron microscope, in this aspect, reflects Nathan Rosenberg's characterization of scientific instruments in general as leading to "interdisciplinary research," the rise of "entirely new subdisciplines," and the "migration" of scientists from one field of study to another. See Nathan Rosenberg, "Scientific Instrumentation and University Research," *Research Policy* 21 (1992): 381–90.

commands the threshold of scientific endeavor in these areas takes on added significance. Simply put, if social factors are important in shaping the technology that has given rise to new fields of science, then these areas of science are, by extension, socially configured to a proportionate extent.

Electron "Lenses" and the First "Choice"

A transmission electron microscope operates in a fashion analogous to a conventional light microscope. Instead of using light as the medium and optical lenses to magnify and focus the image, however, the electron microscope utilizes a "beam" of electrons magnified and focused by either magnetic or electric lenses. An electron moving in a magnetic field changes direction as it moves along a trajectory at right angles with respect to the direction of the magnetic field. The degree to which its direction is changed is inversely proportional to the speed with which it is moving and directly proportional to the strength of the field and the charge on the electron, hence, degree of shift = (constant × charge × field strength)/velocity. Similarly, an electron moving in an electric field changes direction. As a result of the attraction between a positive plate and the negatively charged electron, the electron is drawn toward the plate, hence, degree of shift = (constant × charge × electric field)/velocity.

These, then, are two fundamental ways of "bending" electrons in order to utilize them analogously to light and thus magnify an object.[6] While an electromagnetic electron microscope utilizes a magnetic field, the electrostatic design employs an electric field as its "lens." This choice between lens types presented itself to the first builder of an electron microscope, Ernst Ruska, who, in the late 1920s and early 1930s as a graduate student at the Technological University of Berlin, was studying electron lenses. As Ruska later recognized, however, his choice of the magnetic design was predicated on an incorrect assumption.

When Ruska began examining the relative merits of different electron lenses, he initially misunderstood the properties of an "electrostatic einzel lens," and so he opted in favor of the magnetic design. On the basis of his understanding of how electrons would act in the field of an electrostatic lens, he concluded that they "would not be appreciably altered on passage through the lens because of the symmetrical field distribution about the mid-plane of the lens." Having "overlooked that

[6]In both lens systems, electric currents are used: in the latter case, obviously, to create the electric field, while in the former case, to create an electromagnet, which in turn supplies the magnetic field that acts as the "lens."

as a consequence of the changing electron velocity a strong focussing of the ray bundles occurs," he thus "suggested another arrangement . . . *with spherically-shaped grids.*"[7] As a result, "the images were appreciably *distorted by the two meshes immersed in the beam.* This none-too-pleasing result of the investigation made it seem . . . at the time more fruitful to concentrate on the properties of magnetic lenses."[8] As these remarks reveal, it was the combination of misunderstandings that induced Ruska to abandon the electrostatic system in favor of the magnetic type. Hence, the first choice concerning the electromagnetic and electrostatic lenses was not a result of any real deficiency in the latter.[9]

As a result of what happened in Berlin, however, the electromagnetic lens received a "head start" and, consequently, a measure of technological momentum that made it the front-running technology in the early commercial development of electron microscopes.[10] Because the electron microscope was intended to surpass the resolving power of the light microscope, the momentum that the electromagnetic type received as a result of this episode established it as the leading design in the quest to "see the atom"—an overarching goal of microscopy virtually since the birth of atomic theory.[11]

The lead that the electromagnetic design received as a result of Ruska's choice relegated the electrostatic instrument to playing catch-up in both Germany and America. Because both RCA in America and Siemens in Germany were among the first to initiate electron microscope development, each had an advantage in securing patent positions for the electromagnetic-type design.[12] Siemens began manufacture of electron microscopes in 1939, and RCA began marketing an

[7]Ernst Ruska, *Early Development of Electron Lenses and the Electron Microscope* (Stuttgart, 1980), p. 21, emphasis added.

[8]Ibid.

[9]Ruska also related this episode to his audience in his acceptance speech for the 1986 Nobel Prize in physics. See Ernst Ruska, "The Development of the Electron Microscope and of Electron Microscopy," *Reviews of Modern Physics* 59 (1987): 629.

[10]By "technological momentum" I am referring to the various social and institutional forces in which the electromagnetic technology became embedded from this early point onward. That is, I am using the word "technological" to denote a socially constructed phenomenon as opposed to a "technical" characteristic.

[11]The editors of *Scientific American,* in a piece entitled "Our Point of View," reflected the sentiment of this quest to see smaller and smaller structures of matter. See *Scientific American* 163 (1940): 9. This aim of the microscope is also revealed in S. Bradbury, *Evolution of the Microscope* (New York, 1967). The extent to which this remains a driving goal for scientific instruments is demonstrated by a recent article by Ronald Hoffman, "For the First Time, You Can See Atoms," *American Scientist* 81 (1993): 11.

[12]Reinhold Rudenberg addresses the early patents in Germany in "The Early History of the Electron Microscope" (letter to the editor), *Journal of Applied Physics* 14 (1943): 434.

electron microscope in America in 1941.[13] While unable to surmount the technical advantages RCA held with the electromagnetic microscope, GE adopted a strategy of targeting what its engineers perceived as a need for a "practical commercial instrument."[14]

The question of what results in technological success or failure can be better understood if one explores GE's quest to develop and market such a commercial instrument. Central to such an exploration is determining specifically what factors affected GE's attempt to build and market this instrument. Here, the story turns to the work of C. H. Bachman and Simon Ramo, GE research scientists pursuing the development of the electrostatic electron microscope at the company's Electronics Laboratory in Schenectady, New York.

The Case for the Electrostatic Design

Bachman and Ramo first published word of their intention to build an electrostatic electron microscope in a three-part article in the *Journal of Applied Physics* in 1943. One year earlier and in the same journal, E. G. Ramberg of RCA Labs had published results of research that found that greater aberration effects resulted from the use of electrostatic lenses compared to electromagnetic lenses.[15] Nevertheless, Bachman and Ramo believed that electrostatic lenses would prove to be a more viable system for a "practical commercial instrument."[16] In order to understand fully the factors that went into this decision, familiarity with some of the basic physical properties of electron lenses is essential.

There are two major sources of distortion of the image in electron microscopy: chromatic aberration and spherical aberration. In light optics, aberration refers to an image that is blurred because not all of the light rays from the object are focused at the same distance from the lens. Similarly, in electron optics aberrations are caused by variations in the point at which the electrons, after passing through the lens, converge to form the image. In light optics, aberrations are the result of imperfectly ground lenses and the varying frequencies (which are directly related to velocity in a given medium, e.g., glass) of constituent

[13] Several summations of RCA's development of the electron microscope are available. For the most complete, see Jerome H. Reisner, "An Early History of the Electron Microscope," *Advances in Electronics and Electron Physics* 73 (1989): 163–215.

[14] C. H. Bachman and Simon Ramo, "Electrostatic Electron Microscopy I," *Journal of Applied Physics* 14 (1943): 8.

[15] E. G. Ramberg, "Variation of the Axial Aberration of Electron Lenses with Lens Strength," *Journal of Applied Physics* 13 (1942): 582.

[16] Bachman and Ramo (n. 14 above), p. 8.

colors of the spectrum. Analogously, in electron optics, blurred images, or aberrations, are the result of imperfections in the field lines of the lenses, known as spherical aberration, and variations in electron velocity, or chromatic aberration.[17] Both types of aberration can present difficulties that severely distort the image.[18]

As was explained earlier, the degree to which an electron's direction is changed is a function of its velocity. The velocity of the electron is, in turn, directly related to the voltage of the "electron gun"—as voltage increases, the velocity of the electron increases. If the voltage in the gun varies, the velocity of the electron will increase or decrease accordingly. Consequently, as electrons of varying velocity pass through the lens, the degree to which they are "bent" by the lens will differ. This introduces an aberration effect whereby electrons that represent the object are focused at varying distances from the lens. This effect, chromatic aberration, is illustrated in figure 1. Spherical aberration, the other major source of focusing problems, is caused by variations in the voltage that cause the strength of the fields that constitute the lenses to waver. Similar to the case with imperfectly ground light-optical lenses, electron lenses of varying field strength will cause electron "beams" to be focused at varying distances from the lens. Spherical aberration is illustrated in figure 2.

In order to prevent aberration in an electron-focusing system, the voltage supply must be carefully regulated. Bachman and Ramo recognized, however, that, in the electrostatic lens system, variations of voltage in the "gun" would be offset by proportional variations in the lens system. Consequently, any potential chromatic aberration introduced by the electron gun would be offset by counteracting variations in the lens system, and the need for elaborate voltage regulation would be eliminated. This inherent simplicity of the electrostatic design led Bachman and Ramo to regard this system as well suited for the practical commercial instrument they had in mind.

In outlining their plan, Bachman and Ramo described a microscope characterized by "simplicity of design, operation, and maintenance," having a resolving power ten times greater than the light microscope, and possessing a "size, weight, and complexity less than previously

[17] D. Gabor's *The Electron Microscope* (New York, 1948) provides a good introduction to these concepts.

[18] In addition, there also exists *relativistic* aberration—a more arcane phenomenon that results from the changing mass of the electron as it approaches the speed of light—with which we need not be as concerned because neither system holds an advantage in this regard. For a discussion of the contemporaneous understanding of relativistic aberration, see V. Zworykin et al., *Electron Optics and the Electron Microscope* (New York, 1946), pp. 650–51.

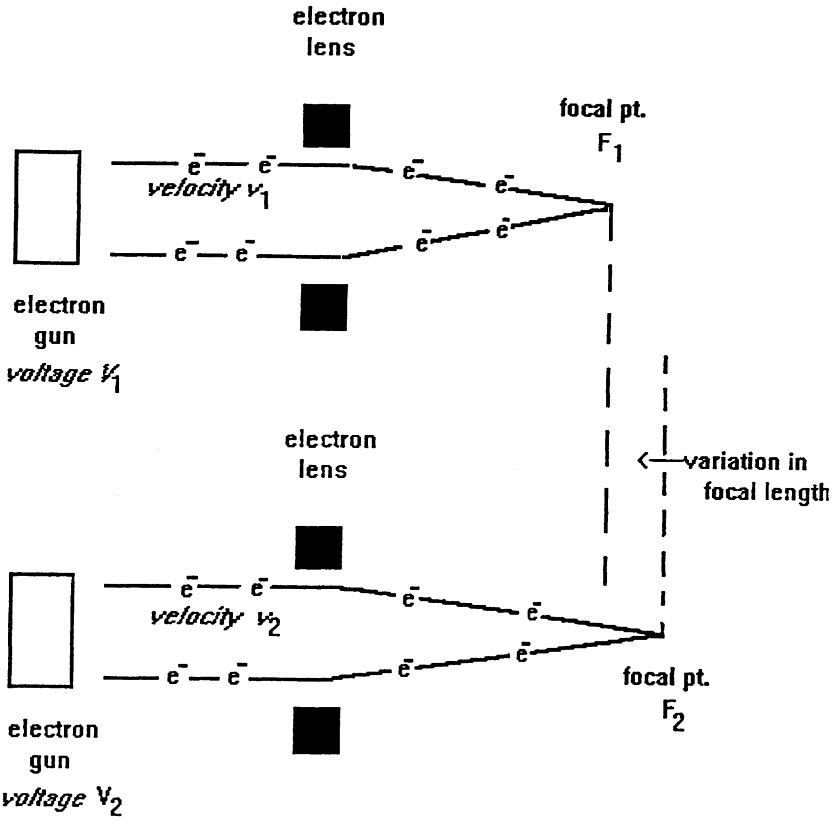

FIG. 1.—Schematic diagram of chromatic aberration. As voltage (*V*) varies, the velocity of electron (*v*) varies; thus, the focal point wavers, causing a "blurring" effect.

described instruments."[19] In formulating the design for their machine, they were willing to achieve simplification at the expense of forgoing the state-of-the-art resolving power then possible for electron microscopes. As a trade-off, they provided a compact and relatively mobile instrument—having a source-to-image distance of 11 inches and mounted on casters in order that it could be rolled from place to place—aimed at offering "care-free use by the operator."[20]

General Electric's attempts in 1944 to produce and market an electron microscope based on this design did not meet with much

[19]C. H. Bachman and S. Ramo, "Electrostatic Electron Microscopy III," *Journal of Applied Physics* 14 (1943): 155.

[20]Ibid.

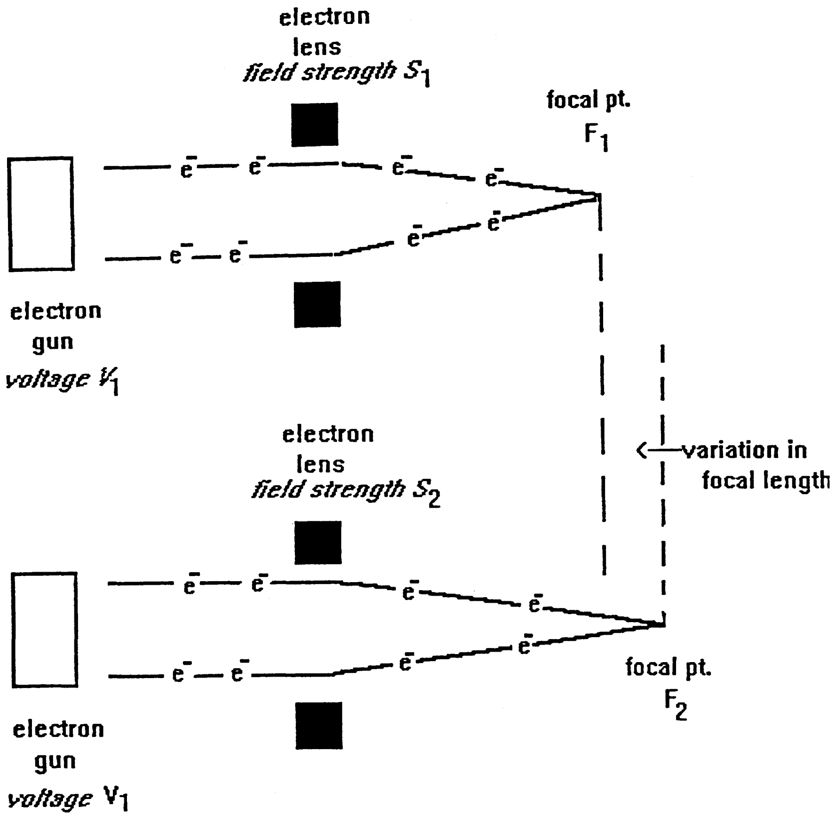

FIG. 2.—Schematic diagram of spherical aberration. As field strength in the lens varies, the focal point wavers, causing a "blurring" effect.

commercial success.[21] Yet it does not appear that its failure was due simply to an inherent inferiority in the performance capabilities of this lens design.[22] Successes achieved internationally demonstrate that the electrostatic design was technically viable and that a market for such machines *did* exist. Before looking at successful ventures in Japan and Germany, however, let us turn to some contemporaneous evaluations of the needs of electron microscopists.

It was not only those at GE who suggested needs other than high resolving power. James Hillier and R. F. Baker, two scientists involved in

[21]Reisner; and Sterling Newberry, "Electron Microscopy, the Early Years: Part I," *EMSA Bulletin* 15, no. 1 (1985): 39.

[22]Keiji Yada, "History of Electron Microscopes, Tohuku University," in *History of Electron Microscopes*, ed. Hiroshi Fujita (Kyoto, 1986), p. 29.

electron microscope development at RCA, criticized evaluating the performance of an instrument by "measuring the least separation observable in a single micrograph [i.e., resolution]," remarking that "such measurements bear little, if any, relationship to the *every-day* performance of a particular instrument."[23] Further, they criticized this criterion of evaluation because it "do[es] not take into account spoilage of micrographs caused by defects of specimen technique, by inaccuracies in the adjustment, and by contamination of the instrument."[24] Although never explicitly stated as such, these latter concerns directly relate to the relative ease of operation of the instrument.

The supposition that the electrostatic instrument was rejected out of hand because it was designed with a lower resolving power is also dubious in light of a 1946 survey conducted by the Electron Microscopy Society of America (EMSA). Responses to a questionnaire indicated that, in over two-thirds of the work in contemporaneous electron microscopy, resolution "could be neglected as a limiting factor."[25] This suggests that microscope users were not constantly pushing the frontiers of resolution and, consequently, were not so dependent on this state-of-the-art aspect of the electron microscope. Even discounting the third of the work that presumably demanded ultimate resolution, a practical instrument offering ease of use and a lower price in lieu of optimal resolving power should have been adequate for a sizable portion of microscope applications. Had it been marketed effectively, such a practical instrument should have been appropriate for tasks such as routine quality-control testing in industry.[26] Such a hypothesis is supported by events on the international scene.

[23]James Hillier and R. F. Baker, "A Discussion of the Illuminating System of the Electron Microscope," *Journal of Applied Physics* 16 (1945): 469 (emphasis in original).

[24]W. G. Kinsinger, J. Hillier, R. G. Picard, and H. W. Zieler, "Report of the Electron Microscope Society of America's Committee on Resolution," *Journal of Applied Physics* 17 (1946): 989.

[25]Ibid.

[26]The need for a simplified machine can be inferred from two letters written to Thomas F. Anderson, RCA electron microscope fellow of the National Research Council working at the RCA labs in Camden, New Jersey, in the early 1940s. John L. Magee of the B. F. Goodrich Corporation wrote to his friend Anderson about problems relating to the installation of a complex machine in a corporate environment: "La Rue of [the] engineering dept. is apparently in charge of installation but the work must be done by the plumbing and electrical departments with equipment which is bought by the purchasing dept., etc., etc." Related to the manpower demands of the complex machine that would be obviated with an easy-to-use instrument, a J. H. Matthews of the University of Wisconsin wrote to Anderson expressing doubt that the university would allocate funds "to get a trained man to work with it," feeling that, with such a complex tool, "the technique is often fully as important as the instrument itself." See Magee to Anderson, April 7, 1942, and Matthews to Anderson, February 25, 1941, Thomas F. Anderson Papers, American Philosophical Society, Philadelphia (hereafter cited as Anderson Papers).

Electrostatic Successes in the International Setting

After World War II, firms in Germany and Japan successfully manufactured and marketed electron microscopes with electrostatic lenses. In Japan, an electrostatic electron microscope was first built by Yasumasa Tani, a researcher at the University of Tokyo, in 1939.[27] Although development was hampered by the aerial bombings and material shortages of World War II, this instrument eventually attained a resolution on an order of magnitude equaling the best of the contemporaneous electromagnetic microscopes and remained in use until 1950.[28]

A development at the Japan Electron Optics Laboratory (JEOL) in Tokyo also demonstrates that contemporary researchers perceived the electrostatic design as technically viable. In September 1946, Kenji Kazato headed a JEOL team that evaluated current electron microscope technology. A group of "first-class scientists from physics, electronics and vacuum technology" chose the electrostatic machine as the most propitious design.[29] Although JEOL would switch to the electromagnetic design years later, the fact that its initial study found the electrostatic design favorable suggests that in the mid-1940s the choice between electrostatic and electromagnetic lenses was not plainly obvious.

Further evidence in support of the viability of electrostatic microscopes is offered by the success the Toshiba Corporation achieved with the electrostatic design. Toshiba successfully built and marketed several electrostatic electron microscopes from 1941 through 1943, including the Toshiba model numbers 1, 3, and 6.[30] These instruments were designed with a maximum resolution of 80 angstroms (Å), or 80×10^{-10} meters. Development and manufacturing continued through the 1940s into the 1950s. In addition to achieving gains in resolving power (the EUL-1B model in 1947 provided 60Å resolution), Toshiba continually implemented new features such as the capability of viewing three different types of images on a single instrument. So equipped, the EUL-1B functioned as a transmission electron microscope and a shadow microscope, as well as offering electron diffraction analysis.[31] In addition to the electrostatic models, Toshiba also produced electromagnetic

[27]Akira Fukami, Koichi Adachi, and Kentaro Asakura, "Development of Electron Microscope in Tokyo Imperial University," in Fujita, ed. (n. 22 above), p. 30.

[28]This microscope's resolution was better than 100Å. An angstrom (Å) is equal to 1×10^{-10} meters. Contemporary electromagnetic microscopes as of December 1943 were performing at about 50Å. See Vladimir Zworykin and James Hillier, "A Compact High Resolving Power Electron Microscope," *Journal of Applied Physics* 14 (1943): 661.

[29]Kazuo Ito, "Development of Electron Microscopes in JEOL," in Fujita, ed., p. 54.

[30]Hiroshi Kamogawa, "Electron Microscope Research in Toshiba Corporation," in Fujita, ed., pp. 64–79.

[31]Ibid., pp. 74–75.

microscopes.[32] Apparently the company felt that neither lens design was necessarily superior for all purposes and that the electrostatic models were clearly suited to existing market demands.

The successes achieved in Japan were echoed in Germany, and perhaps most convincing was the pursuit of the electrostatic electron microscope by the Carl Zeiss Company, a firm already possessing "a great name and international reputation as [a] manufacturer of superior optical microscopes." In 1950 Zeiss performed an evaluation of electron microscope capabilities. Its findings, in combination with its subsequent achievements with the electrostatic design, almost unequivocally demonstrate that this design was perceived as, and indeed was, a practical possibility.[33]

Zeiss researchers cited "lower demands of [the] electrostatic [design] on the stability of the high voltage [electron 'gun'] and the lens current supply," in addition to "cost-saving lens designs" that need "not be water-cooled" (as did electromagnetic lenses). They also noted that "the image is not rotated when the magnification is changed" and concluded that "according to the technical knowledge of around 1950 electron microscopes with electrostatic lenses were certainly up over instruments with electromagnetic lenses in terms of the price/performance ratio." Both independently and in joint ventures with AEG and Suddeutche Laboratorien, Zeiss successfully produced electrostatic electron microscopes from 1942 until 1962.[34]

In the face of these undeniable successes with the electrostatic design on the international scene, GE's hardships in its attempted development of this design require explanation. Clearly it is insufficient to conclude that its failure resulted from the technical inferiorities of the electrostatic lens as compared to the electromagnetic design—no matter what the present (1990s) state of the technology reveals. Therefore, one must delve deeper to reveal the processes involved in this instance of technological choice. Ultimately, the respective successes and failures of the RCA and GE electron microscopes are best explained by taking account of nontechnical factors. This can best be done by viewing how each technological system was situated in what social constructionists have termed the "seamless web" of human activity.[35]

"Success" for RCA and "Failure" at GE

One critical factor at RCA was its special relationship with scientists and researchers either actively or potentially involved with electron

[32]Ibid.

[33]"The History of Electron Microscopy at Carl Zeiss," in Fujita, ed., p. 209.

[34]Ibid., pp. 210–11; and Cecil E. Hall, "Commercial Electron Microscopes," in his *Introduction to Electron Microscopy* (New York, 1953), pp. 201–25.

[35]Bijker et al., eds. (n. 4 above), p. 3 and passim.

microscopy. This special relationship with the newly emerging community of practitioners is evidenced by the role RCA's leading scientist in the field, James Hillier, played at early EMSA meetings. Another critical factor was the presence of Thomas Anderson, a National Research Council (NRC) fellow, for whom a specific laboratory for electron microscopy was established at RCA.[36] The roles of Hillier and Anderson served two purposes that have relevance to this story. First, Hillier's visible presence at gatherings of electron microscopists provided market linkages to potential customers. Second, Anderson's lab in combination with Hillier's visibility helped establish the credibility of the technology and, more specifically, RCA's instrument, in the eyes of the scientific community.

RCA fostered and openly encouraged relations with users and potential users of the electron microscope. As evidenced by Anderson's work, establishing the usefulness of the instrument to science was a large part of the practical as well as the philosophical aims of electron microscope development at RCA.[37] In 1940, the NRC awarded Anderson a research fellowship to "explor[e] the possibility that the newly developed electron microscope might have applications in biology."[38] In addition to the basic-research value of the NRC fellowship, RCA, not surprisingly, sought to reap commercial rewards from the arrangement. This is demonstrated in the explicit terms under which the fellowship was set up, as outlined in an agreement between Ross Harrison, director of the NRC, and Vladimir Zworykin, director of electronics research at RCA. The agreement provided that RCA would contribute $3,000 for Anderson's salary, while it was "understood that technical credit will be given to the RCA Manufacturing Company in publications." Further, RCA and the NRC agreed that "patentable discoveries, developments in the nature of physical improvement of the instrument, its mechanical adaptation for biological work and methods relating to the mounting of specimens are to be the property of the RCA Manufacturing Company."[39]

[36]See Sterling Newberry, "Electron Microscopy, the Early Years: Part II," *EMSA Bulletin* 15, no. 2 (1985): 39, for the importance of this in the context of competition between RCA and GE.

[37]Hillier recalled that the feeling that the electron microscope should be pursued for philanthropic reasons was always present, and this emphasis, he remembered rather fondly, was specifically encouraged by David Sarnoff, president of RCA (personal interview, September 1991).

[38]Thomas F. Anderson, "Memories of Research," *Annual Review of Microbiology* 29 (1975): 7. For more information on the fellowship, see Reisner (n. 13 above), esp. pp. 225–27; and also Thomas Anderson, "Electron Microscopy of Phages," in *Phage and the Origins of Molecular Biology*, ed. John Cairns, Gunther Stent, and James Watson (Cold Spring Harbor, N.Y., 1966), pp. 63–78.

[39]Ross Harrison to Vladimir Zworykin, June 17, 1940, Anderson Papers.

Anderson's lab at RCA was, from its inception in early 1941, involved in scientific research and publication in matters related to electron microscopy. The first images of viruses viewed with RCA's developmental model received much attention in both the scientific and popular literature.[40] Thus, as the work at RCA was made known to outside groups, RCA became identified with state-of-the-art microscopy. The linkages to relevant scientific circles established a social milieu, or "technological frame," that increased the likelihood of commercial success with the instrument.[41] RCA's consciousness of the public-relations value of Anderson's work is made quite clear in a letter from M. C. Banca, of the company's Engineering Products Division, requesting Anderson's signature to release use of pictures he made on the electron microscope. Wondering if Anderson "had forgotten about it," Banca explained that "we are rather anxious to use this for publicity."[42]

People affiliated with the applications of the RCA electron microscope, including the directors of the fellowship and others from industry and academia, came from all over the country.[43] The prestige of these scientists and their institutions reflects the institutional linkages and personal interactions that were undeniably important in fostering a respected position for RCA in the nascent field of electron microscopy.[44]

[40]For example, S. Luria and T. F. Anderson, "The Identification and Characterization of Bacteriophages with the Electron Microscope," *Proceedings of the National Academy of Sciences* 28 (1942): 127–30; S. Luria, M. Delbruck, and T. F. Anderson, "Electron Microscope Studies of Bacterial Viruses," *Journal of Bacteriology* 46 (1943): 57–77; Stuart Mudd, Katherine Polevitzky, Thomas Anderson, and Leslie Chambers, "Bacterial Morphology as Shown by the Electron Microscope," *Journal of Bacteriology* 42 (1941): 251–64; Wendell Stanley and Thomas Anderson, "A Study of Purified Viruses with the Electron Microscope," *Journal of Biological Chemistry* 139 (1941): 325–38; Thomas Anderson, "The Study of Colloids with the Electron Microscope," *Advances in Colloid Science* 1 (1942): 353–90; Thomas Anderson and Wendell Stanley, "A Study by Means of the Electron Microscope of the Reaction between Tobacco Mosaic Virus and Its Antiserum," *Journal of Biological Chemistry* 139 (1941): 339–44; Glenn Richards, Thomas Anderson, and Robert Hance, "A Microtome Sectioning Technique for Electron Microscopy . . . ," *Proceedings of the Society for Experimental and Biological Medicine* 51 (1942): 148–52; and "Never Seen Before: EM Reveals Viruses for First Time," *Scientific American* 164 (1941): 358.

[41]"Technological frame" is the term Wiebe Bijker employs to denote the combination of social and technical factors that constitute a given "technology." Its applicability to the case of the electron microscope will be elaborated below. See Wiebe Bijker, "The Social Construction of Bakelite: Toward a Theory of Invention," in Bijker et al., eds. (n. 4 above).

[42]M. C. Banca to Anderson, November 17, 1942, Anderson Papers.

[43]Anderson's correspondence from the period of his fellowship, as well as names listed on a guest register, reveal that those interested in the electron microscope and those who sent or delivered material to be examined on the machine were from places as diverse as New York City; Pasadena, Calif.; Dallas; Madison, Wis.; and Portland, Maine, to name just a fw.

[44]Diana Crane, who has explored and revealed the significance of networks of scientists, i.e., "invisible colleges," has found that communications among scientists are influential in

Those individuals with whom Anderson recalls being involved in the biological applications of the electron microscope at RCA include Stuart Mudd, concurrently a professor of bacteriology at the Henry Phipps Institute in Philadelphia; Charles W. Metz, a professor of zoology at the University of Pennsylvania and the director of its Zoological Labs from 1940 to 1945; the preeminent Ross G. Harrison, chairman of the NRC from 1938 to 1946, a professor emeritus of biology at Yale and also concurrently an emeritus trustee at Woods Hole; Wendell M. Stanley, an associate member of the Rockefeller Institute and contemporaneously a visiting lecturer of virology at the University of California (1940), Cornell (1942), and Princeton (1942) and a Nobel Prize recipient in 1946; David B. Lackman, an associate instructor of bacteriology at the Medical School of Pennsylvania from 1939 to 1941 and an assistant bacteriologist for the U.S. Public Health Service from 1941 to 1946 who would later go on to become the senior scientist and scientific director of that agency in 1946; S. E. Luria, a resident assistant surgeon at the College of Physicians and Surgeons, Columbia University (1940–42) and later a Guggenheim fellow in bacteriology at Princeton (1942–43); Harry Morton, a professor of bacteriology at the Medical School of Pennsylvania; renowned physicist Max Delbruck, then a professor at the Vanderbilt Institute of Physics; and also Leslie Chambers, a biophysicist at the Medical School of Pennsylvania, who in 1946 would become the chief physical scientist of the Defense Division Biological Labs.[45]

People at RCA were not only cognizant of the commercial contacts established by Anderson's lab, they were also concerned with utilizing Anderson's experimental microscope specifically for demonstrations to prospective customers. In November 1941, at the end of Anderson's first year at RCA, the RCA project engineer and the sales department arranged a new schedule of microscope allocation to "better accommodate" the demonstration of the machine to "prospective customers" in coordination with the time required for Anderson's research. Not only was one week out of each month set aside, an hour was reserved for

the growth of scientific knowledge in newly emerging fields of study. Crane's findings with respect to scientific developments seem to be paralleled by the technological development of the electron microscope—particularly insofar as this instrument served, and continues to serve, as a technological frontier to scientific advance and, indeed, as we may judge electron microscopy as a field of scientific study. The applicability of Crane's analysis is especially appropriate in light of the existing circle of practitioners centered about the RCA instrument. See Diana Crane, *Invisible Colleges* (Chicago, 1972).

[45]Anderson, "Memories of Research" (n. 38 above). Affiliations of individuals are gleaned from Jacques Cattell Press, ed., *American Men and Women of Science* (New York, 1971–86).

demonstrating the instrument to prospective customers even on days established for Anderson's research.[46]

The network of individuals important for RCA's success also reached beyond Anderson's lab. The involvement of many other RCA scientists with the EMSA provides further evidence of the company's close-knit relationship with the inchoate electron microscope community.[47] Furthermore, Vladimir Zworykin, the director of electronics research who assembled the team to develop the microscope at RCA, also took a keen interest in the success of electron microscope development, having been personally involved in electron optics research at least since the early 1930s.[48] Thus, Zworykin, Banca, and Hillier were all enthusiastically involved in securing success for the RCA efforts.

General Electric, in contrast to RCA, did not cultivate such a congenial relationship with relevant scientific circles. In his recollections of the early days of electron microscopy, Sterling Newberry, head of electron microscope development at GE in the late 1940s (after Bachman and Ramo left), gives a description of his company that is quite different from the approach of RCA. According to Newberry, GE's personnel were much less visible in these early electron microscopy gatherings. For instance, at the second meeting of EMSA in Chicago, Newberry recalls that no GE scientist gave any formal paper.[49] From this, it can be inferred that GE was not utilizing this assemblage of practitioners as effectively as was RCA. Indeed, as Newberry remembers, EMSA's third meeting, held at Princeton University in late 1945, was virtually run by RCA's leading electron microscope scientist, James Hillier.

[46]Memorandum from Perry C. Smith, project engineer, to J. P. Taylor, engineering products sales, with carbon copy sent to Anderson, November 17, 1941, Anderson Papers.

[47]Newberry, "Electron Microscopy, the Early Years: Part II" (n. 36 above), p. 39. The first meeting of EMSA was held in Chicago in 1941, sponsored by the American Chemical Society.

[48]The importance of Zworykin in serving as a conduit between management and the electronics lab is attested by George Morton, a contemporary scientist at RCA labs in the 1940s. Morton describes Zworykin as "one of those rare and invaluable men who can command the trust and aid of top management (i.e. for funding, etc.) and at the same time have the respect, loyalty and cooperation of those under him." Correspondence between Morton and Eric Weiss, a scientist involved in electron microscope development at RCA, February 8, 1993. I am indebted to Mr. Weiss for a copy of this letter and other insights into "laboratory life" at RCA. In addition to serving as a conduit within the company, Zworykin also championed the microscope outside RCA, notably in a lecture entitled "The Electron Microscope in Relation to Chemical Research," delivered at the first EMSA meeting. Being that, as noted above, the first EMSA meeting was sponsored by the American Chemical Society, Zworykin's choice of topic suggests that he fully realized the significance of this gathering. See Newberry, "Electron Microscopy, the Early Years: Part II," p. 39.

[49]Newberry, p. 43.

Hillier's role in explaining the functioning of his company's instrument and in relating his laboratory's latest findings was undoubtedly important in establishing and buttressing the electron microscope's credibility. As Ian Hacking argues, understanding the physical properties that allow an instrument to work leads one to find its data credible.[50] More important, perhaps, is the image RCA was able to present by having its man, Hillier, recognized as leading the vanguard into this new area of scientific inquiry.

Here, then, is a picture of a network of practitioners, and potential customers, that contributed to the development of a positive image for RCA. Undeniably there were direct effects, as these researchers were affiliated with many scientific institutions and were also potential buyers of the new technology. Too, there were indirect benefits of having members of the scientific elite utilize one's technology. As discoveries with the instrument were published in the 1940s, RCA became increasingly identified with electron microscope technology. And as the scientific literature in various fields proliferated, the burgeoning field of electron microscopy became increasingly identified with RCA. Although these effects cannot be directly measured other than by citing the number of publications mentioning RCA instruments and suggesting the positive correlation to RCA's business success vis-à-vis GE, it is nevertheless self-evident that the establishment of a "good name" is essential for commercial success.[51] This RCA achieved by ensconcing its technology in colleges of practitioners—both visible colleges, as outlined by the institutional affiliations of the individuals listed above, with direct and tangible results, and invisible colleges, as their relations and communications fanned out with more indirect, but ultimately just as important, effects.

The more indirect influences of RCA's involvement with the relevant community of practitioners in electron microscopy are best explained utilizing the notion of "inclusion" as articulated by Wiebe Bijker; that is, the extent to which relevant players who might contribute to the acceptance of a given technology are literally included in the social network in which that artifact is to find its place.[52] As RCA attempted to develop an electron microscope, there were various social groups,

[50]Conversely, if an instrument remains an opaque "black box," its data are likely to be interpreted as artifacts of the machine. See Ian Hacking, *Representing and Intervening* (New York, 1983), p. 209.

[51]For the dangers inherent in trying to reduce technological successes and failures to a single factor in relation to the electric car, see Michel Callon, "Society in the Making: The Study of Technology as a Tool for Sociological Analysis," in Bijker et al., eds. (n. 4 above), p. 95.

[52]Bijker (n. 41 above).

scientific theories, and technological artifacts that constituted the "technological frame" in which the instrument existed—really, this technological frame *is* the electron microscope in the broadest sense of its existence in the sociotechnical world. As such, the human actors in this setting were indeed a significant element in determining the "success" of the instrument, and RCA, by literally "including" so many important actors in its technological frame, helped provide a viable subculture in which the artifact could flourish.

The actors involved here varied both in their orientation and in their level of inclusion. Obviously RCA's own scientists, men like Hillier, were directly grounded in electron microscope science; this GE had as well, with Bachman and Ramo and, later, Sterling Newberry. But RCA's relative prowess lay in the level of inclusion of actors with other groundings, most notably actors from the life sciences tied to RCA via Anderson's lab, including Anderson himself. Especially important was the extent to which RCA's relationship to the scientific community resulted in users becoming increasingly familiar and dependent on the RCA machine.[53]

Another key element in RCA's technological frame was the high level of inclusion of the business side of the corporation, most notably and convincingly demonstrated by the financial and emotive support offered by David Sarnoff, president of the company.[54] Sarnoff's support emanated directly from a very high opinion of electron research that went above and beyond concern for the commercial success or failure of the electron microscope. In the words of his biographer, Kenneth Bilby, Sarnoff envisioned "a total system approach to a new industry—'the whole ball of wax' he called it—and at the time it was unique in the industrial landscape. . . . From this concept, Sarnoff moved on to an ever more dynamic gestalt for the management of technology, which he began articulating during the mid-thirties in speeches and at stockholder meetings. *Fortune* would later call it his 'missionary approach to the science of electronics.' RCA would muster all its research resources behind the electron."[55]

Reflecting on RCA's accomplishments in the mid-1950s, Sarnoff echoed this sentiment, remarking, "we are an organization founded upon science. We made our living by the tiniest thing known in the

[53]Direct evidence of this occurring is attested to by a 1942 letter to Anderson from G. C. Clark of the Chemistry Department at the University of Illinois. Clark, who was involved in setting up a national meeting of electron microscope users, admitted to Anderson that "most of us [electron microscope users] obviously depend on the RCA instrument" (G. C. Clark to Anderson, November 2, 1942, Anderson Papers).

[54]See n. 37 above.

[55]Kenneth Bilby, *The General: David Sarnoff and the Rise of the Communications Industry* (New York, 1986), pp. 124–25.

world, the tiniest particle that scientists know about—the electron."[56] That Sarnoff's emphasis on the importance of electron research contributed directly to the development of the electron microscope is evidenced by the personal interest he took in the project and by specific references to the microscope in public addresses. For instance, in a 1943 speech outlining RCA's accomplishments, Sarnoff noted, "we have the electron microscope, one of the most important new scientific tools of the twentieth century."[57] It was thus the relative advantages of the technological frame about the electron microscope at RCA that proved most advantageous in its competition with GE and consequently determined the "success" of the electromagnetic configuration.

Evidence of direct competition between GE and RCA is noted by Newberry, who was a pioneer in early electron microscope development at Washington University in St. Louis in the 1930s and would be hired by GE in 1947 to head its "second attempt" at developing an electrostatic microscope. Newberry, on recalling the 1943 meeting of EMSA, relates that each company was "obviously partisan" with respect to its own machine and, further, suggests that competition at that time was especially marked regarding GE's development of a portable electrostatic microscope.[58] While both companies were vying for recognition of their technologies, RCA clearly utilized such occasions more advantageously. That the RCA instrument should have reaped greater commercial success should perhaps come as no surprise.

It is important to note here that neither at this 1943 meeting nor at any of the other early meetings was there a situation where one company's instrument outperformed the other and thereby won support. On the contrary, as Newberry states regarding the 1943 EMSA meeting, "there were difficulties for both [RCA and GE] instrument displays . . . [consequently] there was no attempt to display instruments for several meetings after this one."[59] Thus, it is insofar as scientific, business, and professional relationships were developed that these meetings translated into commercial success.

In addition to RCA's advantageous relationship with the scientific community, the company's internal approach to electron microscope

[56]David Sarnoff, "Remarks at a Dinner Honoring Dr. Vladimir K. Zworykin," in his *Looking Ahead: The Papers of David Sarnoff* (New York, 1968), p. 254.

[57]David Sarnoff, "Address before the American Association for the Advancement of Science," Lancaster, Pa., November 11, 1943, in ibid. Hillier also spoke of Sarnoff's personal interest in the course of an interview with the author in September 1991. It is also noteworthy that at a dinner honoring Vladimir Zworykin, the acclaimed television scientist, Sarnoff noted Zworykin's work on the electron microscope as well as his efforts in television. See ibid., p. 252.

[58]Newberry, "Electron Microscopy, the Early Years: Part II" (n. 36 above), p. 40.

[59]Ibid.

development differed from GE's. Hillier recalls that Sarnoff engendered an environment at RCA that was quite responsive and amenable to the needs of developing the electron microscope.[60] This approach contrasts sharply with Newberry's recollections regarding electron microscope undertakings at GE. In 1944, GE began production of an electrostatic electron microscope based on the design of Bachman and Ramo. While the first ten instruments sold quickly, trouble resulting from hurried design and inadequate machining adversely affected sales of the next "batch" of twenty microscopes. With this sour turn of events, Ramo moved to the West Coast because of his wife's health, and Bachman became discouraged and left for a teaching job at Syracuse University. Thus, the first attempt at commercial production of an electron microscope at GE came to an end. Rather than a technical deficiency of the electrostatic lens design, however, Newberry points to the lack of corporate support.[61]

On his arrival at GE in May 1947, Newberry was told by a former salesman for the electronics lab "that some minor adjustments should have been possible to make them perform to specification."[62] A month later, Newberry was able to uncover the flaws in Bachman and Ramo's design. Examining their notebooks, he found that they had decided, imprudently, to go ahead with a smaller, 2-inch lens design, which introduced a distortion into the image. Newberry concluded from the sketchiness of their notes that Bachman and Ramo were apparently hurrying "under pressure" and had thus performed "no experimental verification . . . before a large program was launched."[63] That Bachman and Ramo would have made such an error in the absence of some outside influence seems highly unlikely, for in outlining their research in February 1943 they specifically acknowledged negative effects that limit "the reduction in diameter of the microscope body for any given lens design."[64]

Investigating further two years later, Newberry found that "critical parts" subcontracted for the production models had "not received the workmanship required by the design."[65] In GE's second attempt to develop and market an electron microscope, moreover, Newberry's efforts would also suffer from a lack of support. In a retrospective appraisal of his years at GE, he alluded to the lack of financial resources

[60]Hillier interview (n. 37 above).

[61]Newberry, "Electron Microscopy, the Early Years: Part II," p. 44.

[62]Ibid.

[63]Ibid.

[64]C. H. Bachman and Simon Ramo, "Electrostatic Electron Microscopy II," *Journal of Applied Physics* 14 (1943): 70.

[65]Newberry, "Electron Microscopy, the Early Years: Part II," p. 45.

made available to electron microscope development, noting specifically how he and his colleagues "used to jokingly say 'as soon as we purchase a proper metal name plate, we have exceeded the allowable manufacturing cost.' " He also referred to difficulty in obtaining a suitable metal cabinet to house the microscope: "The current model of the GE Electric Ironer had an ideal frame for the purpose. . . . However, the Factory would not even consider selling them to us in small numbers because of possible production foulups." He then punctuated this remembrance by noting, "There were many more such disappointments."[66]

Newberry went on to present additional evidence of GE's lack of adequate support, as he related being "sent back to the drawing board with essentially no funds." And perhaps most convincing are his remembrances of having to "devise a self-guiding boring bar similar to those made by *early cannon makers*" and boring the tube for holding the lenses *by hand* for twelve hours because the factory would not provide the requisite machining, all in order to acquire a "not bountiful" extension of funds.[67]

Despite Newberry's formidable effort, GE scrapped the second attempt at electron microscope production due to a corporate reorganization that entailed a "decentralization of special products" which, in turn, brought about the abandonment of "even well established products such as the Analytical Mass Spectrometer."[68] This restructuring is vital to understanding the role the electron microscope played in the broader corporate strategy prevailing at GE in the postwar years. Unlike the convivial environment in which the technology was situated at RCA, at GE the microscope was seen merely as another product, one which either had to yield immediate profits or be eliminated.

After Charles E. Wilson succeeded Gerard Swope as president of GE in the 1940s, he hired Ralph Cordiner to implement a new corporate organization. Although not publicized until the plan had been almost fully implemented with Cordiner's ascension to the presidency at the end of 1950, the restructuring of GE began as early as 1944 and thus had a direct bearing on the fate of the electron microscope there.[69] Decentralization was the essence of Cordiner's reconfiguration. He divided GE into fifty virtually independent divisions or "profit centers." A man with a calculating, "bottom-line" approach, Cordiner was inclined toward bold and sweeping action, as is illustrated by an episode in his brief experience as vice chairman of the War Production Board.

[66]Ibid.

[67]Ibid., emphasis added.

[68]Ibid., p. 46.

[69]"Mr. Wilson at Work," *Fortune* 35 (1947): 121; "Cordiner of General Electric: Reorganization by Pure Reason," *Fortune* 45 (1952): 132.

Apparently miffed by the inefficiency of government, he sought to fire 3,000 civil servants, and when he "found that he couldn't, the fact seemed to induce in him a sort of cold horror." On instituting the reorganization at GE, Cordiner placed stringent profit requirements on each of the divisions, emphasizing immediate and high rates of return on investments. Divisions either had to produce or be cut back.

This proclivity for sweeping action combined with Cordiner's business outlook—shaped by his own experience in appliance sales and merchandising—led to critical changes at GE: decentralization, greater market responsiveness, and a corporate strategy configured around the production and sale of domestic appliances. This new approach was epitomized, on the one hand, by the construction of the massive "Appliance Park" production facility on a 942-acre site near Louisville, Kentucky, in the 1950s.[70] Production for industry, on the other hand, was concentrated on building heavy power equipment. In 1948 the company launched a multibillion-dollar program to build and market apparatus such as turbine generators.[71] As a consequence of this dual focus, specialized electronic products for industry such as leak detectors, X-ray photometers, and mass spectrometers were left out of GE's corporate strategy during just the period when the attempts at electron microscope development were being undertaken.

General Electric's departure from specialized electronic equipment is apparent in the changing nature and emphasis of the company's advertising from the late 1940s into the early 1950s. Trade journals such as *Chemical and Engineering News,* which had included many GE ads in the late 1940s, became conspicuously devoid of such ads by the early 1950s.[72] And the later ads began to differ in tone. The 1940s' ads had emphasized GE's prowess at helping "industry to solve thousands of problems" with "new testing and measuring equipment." They even held out the hope that some particular problem "may justify a development program to create a new product."[73] By early 1950, however, GE's ads were no longer mentioning new development programs, and, rather than urging those in industry to write to the research labs, they instead instructed readers

[70]Robert Slater, *The New GE: How Jack Welch Revived an American Institution* (Homewood, Ill., 1993), pp. 11–12.

[71]Reported in *Fortune* 38 (1948): 8–9.

[72]*Chemical and Engineering News* is mentioned specifically as an example because it had the largest circulation of any periodical in the chemical industry. It kept abreast of new developments in industrial instruments technology and carried rather extensive advertising for industrial electronic equipment, including some ads for RCA's electron microscope. Other journals, such as *Rubber Age* and *Chemical Engineering,* in which GE originally advertised scientific instruments also reflect this trend.

[73]See, e.g., the two-page spread in *Chemical and Engineering News* 26 (1948): 782–83.

to "call your nearest GE sales office."[74] Completing the de-emphasis on electronic products for industry, the ads featured fewer and fewer products until finally disappearing by 1952.

At RCA, Anderson's lab served as an excellent conduit whereby the company could not only make its technology responsive to the needs of users but through its position could also make users dependent on its technology, all the while furthering its reputation in the field. RCA's relationship to the scientific user-community centered around the electron microscope also provided what might be described as a de facto feedback loop for ongoing development of the instrument. An outline of this can be gleaned from a sampling of articles published in journals specializing in scientific instruments, which reveals that electron microscopists were publishing descriptions of modifications and adaptations of their RCA machines.[75] This ongoing improvement taking place *in the field* suggests that the electron microscope was not a product amenable to a strategy of merely being dumped on the market in the hope of generating immediate profits. RCA not only offered accessories to improve performance of instruments previously sold but also published information to enable users themselves to make improvements.[76] It carved out a market niche not simply by producing a superior technical artifact but by setting up and maintaining a frame where users and the producer remained interactive as well.[77] RCA's role as a scientific research leader in electron microscopy, a reputation established in great measure by Anderson's lab, was undoubtedly of great significance in achieving commercial success with the instrument.

[74]See *Chemical and Engineering News* 28 (1950): 1733.

[75]A few examples, with their affiliations, are H. Crane, University of Michigan, "Additional Stabilization for the Beam Current in the RCA Type B Electron Microscope," *Review of Scientific Instruments* 16 (1945): 58; John T. Quynn, Camp Detrick, Md., "Adjustable Aperture for the Electron Microscope—RCA Type EMU," *Review of Scientific Instruments* 19 (1948): 472–73; J. A. Simpson and Alan Van Bronkhorst, National Bureau of Standards, "Modification of the Electron Microscope for Electron Optical Shadow Method," *Review of Scientific Instruments* 21 (1950): 669; and B. O. Heston and P. R. Cutter, University of Oklahoma, "Molecular Diffraction Attachment for RCA Microscope," *Review of Scientific Instruments* 21 (1950): 608.

[76]For instance, RCA Laboratories, "Laboratory Modifications in the RCA Model EMC Electron Microscope," *Review of Scientific Instruments* 21 (1950): 255; and accessories such as "charge neutralizers," "focusing magnifiers," and "self-bias gun kits," announced in the new products section of the *Review of Scientific Instruments* 20 (1949): 844.

[77]Direct interaction between Anderson and users in the field is evident in Anderson's correspondence and his calendar of "informal talks" during his years at the RCA laboratory. For example, in the early 1940s Anderson made appearances throughout the country at various colleges and organizations such as the American Medical Association and American Chemical Society.

In contrast to the situation at RCA, the electron microscope's prospects at GE did not bode well in a company refocusing its strategy toward the popular consumption of domestic appliances. And the electron microscope held no particular fascination with those higher up the corporate ladder at GE. Rather, a scientific instrument like the electron microscope, not in line with broader corporate goals, faced a greatly diminished chance of commercial success.

Conclusion

As this accumulated evidence demonstrates, the fate of the electron microscope at GE must be understood in full context. It cannot be sufficiently explained by simply stating that the electrostatic instrument was technically inferior to the electromagnetic microscope. While this may be the case as the technics of electron microscopy is currently understood half a century later, it does little to elucidate the dynamics of technological development as it was occurring in the nascent days of electron microscopy.

The teleological retrospective argument of "superior technology" does not stand up in the face of international successes with the electrostatic lens design. Equipped with the knowledge that the electrostatic lens was technically viable, we are better able to understand "successes" and "failures" by viewing RCA's relative success as a product of the technological frame about its electromagnetic lens design. A significant factor was the inclusion of relevant practitioners from without and sufficient direct and indirect support from within the corporation. And in contrast to GE, support for the electron microscope at RCA resulted from a corporate approach that was predicated on electron research and thereby saw the electron microscope as a logical and essential component of its corporate strategy.

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