Introduction

HENRY ROWLAND AND AMERICAN PHYSICS

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In 1929 Werner Heisenberg traveled and lectured widely in the "New World" on the quantum mechanics in whose recent formulation he had played such a large part. The experience left him with the distinct impression that American physicists approached their subject with attitudes quite different from his own and from many of his Northern European colleagues. In addition to their straightforwardness, warmth, and optimism, he remarked on something at once attractive and disturbing, namely, their pragmatic attitude toward the new theory. They did not seem to care too much about its revolutionary conceptual and philosophical implications. Instead, they were impressed with it as a new tool to solve problems. Heisenberg found this attitude epitomized in a young experimental physicist at the University of Chicago named Baron Hoag, with whom he went on a fishing trip to remote northern lakes. For Hoag, the difference was that "You Europeans, particulary you Germans, are inclined to treat such new ideas as matters of principle." While in America, "Basically, physicists, even the theorists among them, behave just like the engineer building a new bridge." If the old formulae do not work adequately in the new situation the engineer corrects them. "But the basic engineering principles have remained unchanged. The same seems to be true of modern physics. Perhaps you make the mistake of treating the laws of nature as absolutes, and you are therefore surprised when they have to be changed. To my mind, even the term 'natural law' is a glorification or sanctification of what is basically

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nothing but a practical prescription for dealing with nature in a particular domain."[2]

This engineering attitude, though not unique to American physicists, nor even universal among them, was certainly widespread when Heisenberg wrote. And it has remained alive and well, albeit in a somewhat different form, even after the center of theoretical activity shifted from Europe to America during the 1930s. It is tempting simply to ascribe it to traditional American practicality, Yankee know-how, and pragmatism. But in the case of physics a much more concrete story pertains. George Sweetnam tells an important part of that story in *The Command of Light*, which focuses on Henry Rowland's diffraction grating and on the Hopkins school of physics built up around their use. For under Rowland's leadership, from the beginning of the new institution in 1875 until his death in 1901, Hopkins became by far the most important nursery of physics in America. This preeminence is manifest in the fact that from 1879 to 1901 no less than 165 graduate students studied with Rowland at Hopkins, of whom 43 are distinguished with "stars" in *American Men of Science*. Most came for advance training without taking a degree. Of the 45 students who obtained the Ph.D. 30 are starred.[3]

Thus Rowland's physical laboratory produced a whole generation of physicists who staffed departments emerging throughout the country, and many of them carried his style of work with them. But Rowland was not working in a vacuum. Although he shared the fondness of some historians for casting him in the heroic role of a lone champion of research struggling against the odds to fulfill a vision that few could see, it would be more appropriate to regard Rowland as playing a particularly prominent part in a movement with many actors. The engineering style emerged from their interaction. Perhaps the most salient single fact in this larger picture is that all three of the most famous American physicists of the late nineteenth century—Rowland, Michelson, and Gibbs—began their careers with an engineering orientation. Rowland took his degree in engineering from Rensselaer Polytechnic Institute with a thesis on the stream engine in 1870. Albert A. Michelson honed his skill with optical devices at the Naval Academy in Annapolis, where he graduated in 1873, before embarking on the physics that would earn him the first American Nobel Prize in 1907. A new study of Michelson and some of the younger people from his Chicago

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[2] Werner Heisenberg, *Physics and Beyond: Encounters and Conversations*, trans. A. J. Pomerans (New York, Harper and Row, 1971), 94-95.

[3] Robert Kargon, "Henry Rowland and the Physics Discipline in America," *Vistas in Astronomy*: special issue on *Henry Rowland and Astronomical Spectroscopy: Celebration of the 100th Anniversary of Henry Rowland's Introduction of the Concave Diffraction Grating*, ed. R. C. Henry, D. H. DeVorkin, and Peter Beer, 29, (1986), 131-136, on 131.

department finds "machinic" a good adjective for his physics.[4] Even Josiah Willard Gibbs, that most esoteric of theorists of thermodynamics and statistical mechanics, completed his Ph.D. at Yale in engineering, the first such doctorate awarded there. His dissertation was on nothing so distant from the everyday world as the atomic theory of matter but on a mathematical investigation of the optimal shape of gear teeth. This early training in engineering, however, has not yet been related to his well-known phenomenological and instrumental view of theory.

To get at the significance of engineering in American physics and of Rowland's place in its history, it is useful to consider the formal establishment of the discipline. On 20 May 1899 the American Physical Society was born at Columbia University in New York. The thirty-six men in attendance had responded to a letter from seven of their colleagues.[5] They promptly elected as their President and Vice President the two people who best represent the style of American physics in the process of its formation, Henry Rowland and Albert Michelson, neither of whom actually attended the meeting but who had agreed beforehand to lend their prestige to its offices. (Gibbs, never an organization man, supported the formation of the Society but declined to participate.) Like Rowland and Michelson—respectively, fourth generation heir to an establishment family of Presbyterian clergymen and immigrant Jew—the leading members were anything but uniform in their backgrounds. Michael Pupin, who hosted the meeting at Columbia, embodied the American success story, having transformed himself by hard work and brains from a lone sixteen-year-old Serbian immigrant in New York into an internationally recognized professor of mathematical physics. At the other end of the social spectrum, Arthur Gordon Webster, the real organizer of the meeting, often called the "father" of the Society, was the only son of a prosperous New England family with a Harvard College education.[6] And yet, across these cultural and social divides were many bridges.

One such bridge is evident in the fact that all of the organizers and many of the founding members had either taken their PhDs in Germany or studied there. Like Rowland, they typically studied in Berlin

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[4] David C. Brock, "The Ryersonites: Chicago Physics and Institution-Building, 1875-1925" (dissertation, Princeton University, in preparation).

[5] Melba Phillips, "The American Physical Society: A Survey of its First 50 Years," *American Journal of Physics*, 58, no. 3 (1990), 219-230, reprints the letter and a list of those attending. Minutes of the early meetings are in *Bulletin of the American Physical Society* (published quarterly), ed. J. S. Ames, M. I. Pupin, Ernest Merritt, vols. 1-3 (1899-1902). The constitution, by-laws, and a complete list of members in 1902 is in vol. 3. Later minutes appeared in the *Physical Review*, when it was joined to the Society, beginning with 16 (1903), 173.

[6] Unless otherwise specified, biographical information is from the *Dictionary of Scientific Biography*. For Webster's important role, see Melba Phillips, "Arthur Gordon Webster, Founder of the APS," *Physics Today*, 40, no. 6 (1987), 48-52.

with Hermann Helmholtz (Rowland, Michelson, Pupin, Benjamin Osgood Peirce, Joseph Sweetnam Ames, Webster) but also in Berlin with Kirchhoff (Pupin) or Kundt (Webster) [Add M. F. Magie], in Heidelberg with Quincke (Michelson), in Leipzig with Wiedemann (Benjamin O. Peirce), or in Goettingen with [??] (Edward L. Nichols). Having gone to Germany in the first place to acquire the kind of specialized education in research that was still largely unavailable in the US, these men all returned with an increased ambition to professionalize their activities at home. Their regular complaints about poor laboratory facilities, inadequate mathematics education, and low intellectual standards should perhaps be read less as a measure of miserable conditions in the universities than of their united ambition for themselves and their discipline in a reorganized curriculum. A major move in that direction was the founding in 1893 of the *Physical Review: A Journal of Experimental and Theoretical Physics* by E. L Nichols and Ernest Merritt at Cornell, with the support of the university. Both Nichols and Merritt would soon play leading roles in founding the Physical Society.

The organizers also constituted a network in the private schools of the East Coast, several of them new but all with new ambitions for research in science: Hopkins, Princeton, Columbia, Cornell, Clark, Harvard, plus Chicago. And they were linked by personal friendship and by apprenticeship, especially to Rowland. Webster had served two years as Michelson's assistant at the new Clark University for graduate students in Worcester before taking over the physics department there when Michelson moved to head the new department at the University of Chicago in 1892. J. S. Ames made his entire career (undergraduate, graduate, colleague, and collaborator) with Rowland at Hopkins, the still-new flagship of research, while another collaborator, E. L. Nichols at Cornell, had done a post-doctoral year with him. Beyond the immediate organizers, Harvard's Trowbridge often acknowledged his debt to Rowland's department, acquired as a visiting professor there. His colleague Edwin S. Hall was one of Rowland's prize doctoral students. And at Yale, where an attempt to lure Gibbs away to Hopkins had failed, Rowland's assistant for eight years, Charles Hastings, carried the Hopkins message as department chair from 1884-1915.[7]

Thus the American Physical Society may be said to have been born as an "old-boy" network with the outspoken Webster as its organizing "father," Rowland its symbolic "father," and Michelson its symbolic "uncle." But it was a rapidly growing network which quickly expanded far beyond the old boys. Beginning with 38 mem-

[7] Kargon, "Rowland and the Physics Discipline," 135.

bers in May 1899, it had grown to 58 by December, to 144 in three years and to 282 in six years.[8] Such rapid growth speaks of high demand for physicists and requires once again that we see the role of Rowland and Michelson not so much as the creators of the discipline but as the inspiring models for a community whose rapid expansion and professionalization had sources reaching far beyond their own remarkable contributions. And this recognition leads immediately back to the engineering orientation of the new physics community as providing perhaps its most representative and unifying characteristic.

This view corresponds to the only extended account by a founding member that we have. Frederick Bedell was the younger colleague of Nichols and Merritt at Cornell, whom he joined as the third editor of the *Physical Review.* Bedell took the founding history of the society back to 1876, Rowland's first year at Hopkins and the year of the international exposition in Philadelphia celebrating the centennial of American independence. Above all he remembered Machinery Hall, dominated by a huge 1600 hsp Corliss engine but featuring also the first Edison light bulb, the first Bell telephone, and the first dynamo made in America, by William A. Anthony, professor of physics and electrical engineering at Cornell (later at Cooper Union as a founding member of the Society). These exhibits represented to Bedell a technological transformation of the culture. In retrospect, they also "typified the future of physics in industry and in education in which the Physical Society was destined to play its part." It was the excitement surrounding the inventions and the personalities of these men and others, such as Nikola Tesla and William Stanley, with their alternating current induction motors and transformers, that was driving the rapid growth and professionalization of physics. "The increasing amount of fundamental research at the universities, with increase of staff and equipment, was stimulating, and there arose a need for journals in specialized fields." And it was out of this demand for specialized technical knowledge, in Bedell's view, that the *Physical Review* was born at Cornell in 1893.[9]

In the same year the International Electrical Congress met in Chicago with delegates from all over Europe, including Helmholtz and a number of notable British and French physicist-engineers. Rowland served as President and Nichols as Secretary of the Chamber of Delegates while Webster chaired the Pure Theory Section. Bedell presented a paper and began lifelong friendships with Rowland and Webster. Thus their organizing activities and personal relations with respect to

[8] Frederick Bedell, "What Led to the Founding of the American Physical Society," *Physical Review*, 75 (1949): 1601-1604, on 1604.

[9] Ibid., 1601-2.

electrical engineering presaged those for the Physical Society.[10] Of the mathematically inclined Webster, J. S. Ames observed, "He was as much interested in what one may properly call the engineering side of his subject as in the purely physical one, and his ability was so great that there was no practical field in which he could not venture with great profit to all concerned."[11] Similar associations can be drawn for others among the founding members. Notable is Pupin at Columbia, who returned from Berlin in 1889 to teach mathematical physics in the newly formed department of electrical engineering, where he became professor of electromechanics in 1901. He achieved fame for his mathematical and material inventions in telegraphy and telephony and registered 34 patents during his lifetime.

To recognize the prominence of electrical and mechanical engineering in the physics of the late 19th century is to obtain a somewhat different view than has been usual in the historical literature. We have available two extended treatments; Daniel Kevles's *The Physicists* (1978), still by far the most useful and interesting survey available, and Albert Moyer's *American Physics in Transition* (1983), with a more specialized philosophical aim. For different reasons neither Kevles nor Moyer focused attention on the centrality of machines in the everyday lives and intellectual commitments of American physicists, though both were fully aware that the growth of physics in the universities depended on its service to engineering. Kevles was primarily interested in the institutional development of the new profession by comparison with its established European counterpart. Not unnaturally he contrasted the largely experimental work of the Americans with the theoretical work of many of their brethren overseas. Under this contrast American physicists lacked the capacity for research in mathematical and theoretical physics and therefore limited themselves to experimental and practical work, pursuing a kind of Baconian fact-gathering while reacting to European ideas.[12] This characterization, though correct in a sense, misses the point that the people who did pursue mathematical and theoretical physics did so with an engineering bent and with great confidence in the worth of their enterprise. Webster and Pupin are representative; even the anomalous Gibbs may qualify. Robert Kargon remarks that "American physics seems to have cultivated a curious type of borderland physics-engineer hybrid, not unlike Rowland himself."[13] Or as Hoag put it in 1929 to Heisenberg,

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[10] Ibid., 1603.

[11] Phillips, "Webster," 48.

[12] Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York, Knopf, 1978), e.g., chapter V, "Research and Reform."

[13] Kargon, "Rowland and the Physics Discipline," 136.

even American theoretical physicists "behave just like the engineer building a new bridge."

Heisenberg's discussion of Hoag's remark goes off in a rather philosophical direction, which is another way to discuss interesting subjects while missing the significance of American physics riding on engineering. Albert Moyer has written a perceptive survey of the changing philosophical positions of late nineteenth century American physicists, judging their commitments according to their degree of adherence to or distance from what J. B. Stallo called "atomo-mechanism" in his 1882 critique of modern physics. In this mode of analysis, their empiricist and antimetaphysical sentiments, which with few exceptions were quite unsophisticated philosophically, appear as forms of phenomenalism, operationalism, or positivism rather than attitudes grounded in everyday practice. Like the experiment-theory axis, this one yields summary statements of the fact-gathering sort: "And most [pre-1900 physicists]—Michelson in his ether studies and Rowland in his measurements of the mechanical equivalent of heat—were dedicated to routinely expanding the data base of received mechanical theories."[14] Again, there may be some justice in treating American physics as almost entirely experimental, particularly when seen as an answer to the question of why American physicists contributed little to the new theories of relativity and quantum mechanics yet readily accepted them.

But "expanding the data base" does not capture the self-confident sense of capacity, even muscularity, that animated so many Americans during their great technological and industrial expansion. Rowland never seems to have suffered a moment's doubt abut his own abilities or his enterprise. When he traveled in Germany in 1876 examining laboratory arrangements and instruments for the projected Hopkins laboratory, his comments were as often caustic as admiring. He and his peers brought back from Germany much of value for physics research, but their imports were highly selective. They discarded anything they considered metaphysical speculation, such as atomic theory. Certainly they were playing catch-up, but they were playing by their own rules. Such independence reinforces the view that to a considerable degree they shared a generic set of values rooted in their common appreciation of instrument-based physics, their personal skill in making mechanical and electrical devices, and their commitment to precision measurement as the vehicle of progress. From this more positive perspective, it might well be said that the diffraction gratings and solar wavelength standards that Rowland distributed throughout

[14] Albert E. Moyer, *American Physics in Transition: A History of Conceptual Change in the Late Nineteenth Century* (Los Angeles, Tomash, 1983), 118.

Europe (while keeping his ruling engine secret) were as important to the development of quantum mechanics as, say, J. J. Thomson's theory of the atom.

George Sweetnam does not write about the issues at this broad untextured level, which he would have regarded as too distant from the sources. Instead, he investigates Rowland's actual work in what he calls "laboratory engineering." It was characterized in the first instance by an incomparable ability to invent simple experiments of great sensitivity to reveal physical effects which one could imagine theoretically to exist but which seemed to defy observation. These experiments began with his early attempts in the 1870s to analyze the magnetization of materials in response to a magnetizing force, which after adroit mathematical simplification yielded an "Ohm's law" of magnetization (albeit without hysteresis).[15] With support from Maxwell they also yielded publication in the widely read *Philosophical Magazine* and the offer in 1875 from Daniel Coit Gilman, President of Hopkins, to head the new research laboratory there. Rowland's electromagnetic experiments continued with his remarkable demonstration, carried out while working in Helmholtz's laboratory, of electromagnetism produced by convection of static charge. That accomplishment immediately established his international reputation. It was followed in 1879 by the equally famous demonstration, carried out by his student E. H. Hall at Hopkins, of the effect of a magnetic field on a current flowing perpendicular to it, the "Hall Effect."[16]

These experiments of sensitivity were matched by Rowland's experiments of precision. His first major project at Hopkin's after returning from his European tour was a redetermination of the mechanical equivalent of heat. He had learned to regard this number as the single most important constant in the new energy physics that had been developing since mid-century and one of the key elements in the attempt to establish an international system of units based on the exchange relations connecting the various branches of physics: mechanics, heat, electricity, magnetism, and light.[17] Ultimately even more important to Rowland in this enterprise of quantitative unification was measuring the wavelengths of the unique spectral lines emitted by "atoms," what-

[15] John D. Miller, "Rowland's Physics," *Physics Today*, 29, no. 7 (1976): 39-45.

[16] Jed Z. Buchwald, *From Maxwell to Microphysics; Aspects of Electromagnetic Theory in the Last Quarter of the Nineteenth Century* (Chicago, University of Chicago Press, 1985): 73-95, gives extended discussion of the discovery of the Hall Effect.

[17] H. Otto Sibum, "An Old Hand in a New System," in Jean-Paul Gaudillere, Illana Lowy (eds) *The Invisible Industrialist: Manufactures and the Production of Scientific Knowledge* (London, Macmillan, 1998), pp. 23-57. Sibum is completing a book on measurements of the mechanical equivalent of heat which will include an extended discussion of Rowland's work, its sources and context.

ever they might be, and showing that these markers were the same throughout the terrestrial and celestial realms. Using prism spectroscopes to separate the spectral lines, Bunsen, Kirchhoff, and others had established this project in the 50s and 60s. A. J. Ångström used plane diffraction gratings in the 1860s to obtain some precision in measuring wavelengths and at least two American acquaintances of Rowland make progress in perfecting the technique.[18] But it was Rowland himself who astonished the world with his concave diffraction gratings and standardizing solar spectra. It is of this work and the school of physics which grew up around it and beyond it that Sweetnam writes. Among his most significant findings is the role played by the diffraction gratings themselves, in all their material and mechanical concreteness, as carriers of the school.

Sweetnam's focus on the material means and the personal motivation for attaining sensitivity and precision draws out two features of American physics to which recent scholarship has paid increasing attention: cultural values and technology. On the values side, laboratory discipline, constant pursuit of sources of error, and avoidance of speculation were widely represented not only as imperatives for research but as exemplary moral imperatives, as models for building the character traits of humility, integrity, and strength, or what one used to call the protestant ethic. Rowland, descended from three successive generations of Presbyterian ministers, advertised this idealistic vision of physics in numerous lectures, most famously in his "Plea for Pure Science" delivered in 1883 to the AAAS and continuing through his Presidential address at the second meeting of the American Physical Society in 1899. But the moral ideal as he and other scientists advocated it was grounded in practical laboratory work with materials and machines, in engagement with the real world. In a nearly seamless manner it merged the conditions for moral leadership in society with those for material progress. "Nearly" is an important qualifier, for it became crucial to separate crass material motives, or profit, from the pure quest for knowledge of matter, which might well yield profits when exploited. This tenuous merger of morality and matter required considerable readjustment in the values of elite universities like Harvard, Princeton, and Yale in order to incorporate into their traditional religious and intellectual mission the science and engineering school that they had so consciously kept separate. The problem was by no means unique to America. Maxwell faced much the

[18] Deborah Jean Warner, "Rowland's Gratings: Contemporary Technology," *Vistas in Astronomy*: special issue on *Henry Rowland and Astronomical Spectroscopy; Celebration of the 100th Anniversary of Henry Rowland's Introduction of the Concave Diffraction Grating*, ed. R. D. Henry, D. H. DeVorkin, and Pter Beer, 29 (1986), 125-130.

same challenge at Cambridge University when in 1873 he began to integrate the workshop-like atmosphere of the new Cavendish Laboratory into the gentlemanly traditions of the university.[19] In Germany great school debates raged through the end of the century over modernizing the classical *Gymnasia*. But the merger seems to have found more fruitful ground in the US through the technological and managerial accomplishments that were powering both cultural optimism and industrial expansion.

As Sweetnam and others show, the sensitivity and precision of Rowland's "laboratory engineering" depended not only on his own considerable talent as an inventor but on his intimate familiarity with the practical methods of contemporary machine building and on his access to people even more involved than he.[20] His ruling engine for diffraction gratings would have been inconceivable without the very recent developments in the machine tool industry that had increased the accuracy and precision of machining by two orders of magnitude and that, along with rigorous oversight and quality control, had made possible the mass manufacture of interchangeable parts in the "American system."[21] Indeed, his own ruling engine built directly on that of William A. Rogers, the Harvard astronomer best known for his work with George M. Bond of Pratt and Whitney on the Rogers-Bond comparator, which set the standard in the machine tool industry with an accuracy of one millionth of an inch.[22] In addition he relied heavily on his master mechanic Theodore Schneider for the construction, maintenance, and operation of the engine and on the precision instrument maker John A. Brashear to supply the speculum metal blanks on which the gratings were ruled. In short, the professor, his mechanic, his machines, and his materials all expressed in their various ways the technological-industrial revolution taking place in America.

From this perspective, and taking Rowland as representative, the practical emphasis of American physicists, their rejection of theoretical speculation in favor of a pragmatic use of theory, concrete mechanical

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[19] Simon Schaffer, "A Manufactory of Ohms: Late Victorian Metrology and its Instrumentation," in Susan Cozzens and Robert Bud, eds. *Invisible Connexions* (Bellingham: SPIE, 1992), 23-56. Idem., "Accurate Measurement is an English Science," in M. N. Wise, ed., *The Values of Precision* (Princeton, Princeton University Press, 1995), 135-172.

[20] George Sweetnam, "Henry Rowland, the Concave Diffraction Grating, and the Analysis of Light," in M. N. Wise, ed., *The Values of Precision* (Princeton, Princeton University Press, 1995), 283-310.

[21] Paul Uselding, "Measuring Techniques and manufacturing Practice," in Otto Mayr and R. D. Post, eds, *Yankee Enterprise: The Rise of the American System of Manufactures* (Washington, D.C., 1981), 103-126; and in the same volume, David A. Hounshell, "The System: Theory and Practice," 127-152.

[22] Warner, "Rowland's Gratings" shows that all ruling engines in the 19th century were adapted directly from dividing engines used in making precision machinery and scales.

models, and precision measurement, looks like a preference for exploiting resources in which they possessed an evident advantage while devaluing theoretical and philosophical traditions which they lacked. Certainly the decision to pursue precision measurement as the most productive route into the future of physics was a conscious one for both Rowland and Michelson and they organized their laboratories around it. Their practicality was not of the chewing gum and sealing wax variety but of cutting edge technologies and professionally crafted instruments.

Again from this perspective, Rowland's repeated pleas for pure science look as much like a fear that his colleagues could all too easily turn their enterprise into an Edisonian science of profits as it was a critique of Edison's own activities.[23] That is, the pressing need to demarcate pure from applied science seems to have arisen simultaneously with the recognition that the requirements for technological development and for research science were much the same and with the threat that the research laboratory might well be mistaken for a factory, both architecturally and intellectually.

George Sweetnam's study of *The Command of Light* explores the everyday practices and attitudes that characterized the Hopkins school of physics. It thereby raises issues of quite general import about Rowland's representative position in American physics. These issues will provide ground and stimulation for many further such studies.

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[23] David A. Hounshell, "Edison and the Pure Science Ideal in 19th Century America," *Science*, 207 (1980): 612-617.