FOUNDING THE NATIONAL BUREAU OF STANDARDS (1901–10)

CHAPTER II

SAMUEL WESLEY STRATTON

For much of its first decade and a half, until shortly before America's entry into World War I, the Bureau's energies were almost wholly engaged in developing its staff and organization, establishing new and much needed standards for science and industry, and proving itself as a valuable adjunct of Government and industry. It assumed responsibilities as readily as it accepted those thrust upon it, and found them proliferating at a rate faster than the Bureau could grow. In 1914, making its first pause to take stock, the Bureau discovered that it had virtually to rewrite the functions of the organic act that had created it. This is the story told in the next two chapters.

From the day he arrived in Washington, Samuel Wesley Stratton (1861–1931) was the driving force behind the shaping of the National Bureau of Standards. Louis A. Fischer and Dr. Frank A. Wolff, Jr., who had been with the Office of Weights and Measures since 1880 and 1897, respectively, and had friends and acquaintances who knew many members of Congress, did much of the work of bringing the proposed bill to the favorable attention of members in both Houses. But it was Stratton, enlisting the aid of other scientists and officials in the Government, who drafted the text of Secretary Gage's letter, prepared the arguments that were to persuade Congress, and secured the imposing and unprecedented array of endorsements for the proposed laboratory.[1]

At his very first meeting on Capitol Hill, Stratton "mesmerized the House Committee," Wolff recalled, "and splendid hearings were held which were printed for distribution without stint." [2] He was to be the director of the Bureau for the next 21 years.

As a youth, Stratton's interest in machines and mechanical processes led him to major in mechanical engineering when he entered the University of Illinois in 1880. With his bachelor of science degree and a summer of intensive reading in Ganot's Physics—the training text of so many 19th-century American physicists—he was appointed instructor of mathematics and physics in the fall of 1884. In 1889 he was promoted to assistant pro-

[1] Stratton's correspondence on behalf of the bill may be found in Box 1 of the Stratton Papers in the Archives Library of the Massachusetts Institute of Technology.
[2] Speech, Dr. Frank A. Wolff, 25th anniversary of the NBS, Dec. 4, 1926.

Dr. Stratton at his desk in South building, 1905. The Bureau was still in its infancy, but already, according to Rosa, second only to the great German Reichsanstalt among government standards laboratories. The portrait of Michael Faraday on the wall, symbolizing the age of electricty, did not come down until 1950.

fessor of physics and electrical engineering, another subject he acquired on his own.

In 1892 the University of Chicago opened its doors, startling the academic world by paying its head professors "the princely salaries, for those days, of $7,000 each." [3] At the invitation of the renowned experimental physicist, Albert A. Michelson, then organizing his department at Chicago, Stratton came as assistant professor of physics, his salary of $2,000 as great a persuasion as the opportunity to work with Michelson.

Although Stratton, in addition to his teaching, worked on numerous experiments with Michelson or at his direction, and was promoted to associate professor in 1895 and to full professor in 1900, the association was not a happy one. According to Robert A. Millikan, who came to the university in 1896 as a $900 instructor in physics, Michelson was an intense individualist and did not like cooperative ventures in the laboratory. His absorption in his scientific work made him wholly indifferent to people in general and almost impossible to work with. As he once told Millikan, he wanted only a hired assistant who would do just as he was told, not expect any credit for himself, or make any demands other than to ask for his pay check. For Stratton who was outgoing, accessible, and without a trace of affectation, it must have been difficult, and as director of the National Bureau of Standards he was never to forget the Chicago lesson.[4]

How much of Stratton's work at Chicago came out in the stream of papers Michelson published is impossible to say, but at least two bore both their names, one on a new form of harmonic analyzer, a device for high-precision measurement of electrical frequencies, the other a note on the sources of X rays.[5] Millikan, a supreme egoist himself, was to say that he—

> never collaborated with Professor Michelson in any of his researches as both of my predecessors, Professors Wadsworth and Stratton, had done with somewhat unfortunate results in both cases. He never used me as an assistant, as he did some of the younger members of the staff. When Professor Stratton left about 1900 to assume directorship of the Bureau of Standards he warned me that my "turn would come next," meaning, of course, that friction would develop.[6]

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[3] The Autobiography of Robert A. Millikan, p. 224.

[4] Ibid., pp. 87–88; s.v., S. C. Prescott, "Stratton," DAB.

[5] Michelson and Stratton, "Harmonic analyzer," Am. J. Sci., 5, 1–12 (1898); "Source of X-rays," Science, 3, 694–696 (1896).

Stratton's principal research efforts in Michelson's laboratory were in interferometry, he said later, "the field of measurement in which I am personally interested and in which I was engaged when called to take charge of the bureau" (Hearings * * * 1923, Nov. 16, 1922, p. 191).

[6] Millikan, Autobiography, p. 86.

Commissioned in the Illinois naval militia unit that Michelson organized in 1895, Stratton first left the University of Chicago in the spring of 1898 to serve as a Navy lieutenant in the Spanish-American War. He returned to the University that fall. Soon after, Arthur E. Kennelly, the Harvard dean of electrical engineering, said in his memoir of Stratton, he was asked to go to Washington to invite Admiral Dewey and Secretary Gage of the Treasury to give addresses at Chicago, and on that occasion fell into a discussion with Gage about weights and measures and the scientific work being done on them in the national laboratories abroad.[7] Lyman Gage therefore knew Stratton when the Assistant Secretary, Frank Vanderlip, in the summer of 1899 brought up his name as the man to take charge of the faltering Office of Weights and Measures, and invited him to Washington. As Stratton recalled it:

> While on a visit to Washington in 1899, the Secretary of the Treasury asked me to accept a position as head of the Office of Weights and Measures in the Coast and Geodetic Survey, which was declined. However, I pointed out to the Secretary, the Assistant Secretary, and the Superintendent of the Coast Survey the necessity for a government bureau having to do with standards and methods of measurement in the broad sense, and at the request of the Secretary of the Treasury drew up a plan for the establishment of such an institution. I agreed to devote a year's vacation [sabbatical], upon which I was just entering, to the preliminary steps for the establishment of the institution, the first of which was the securing of the necessary legislation.[8]

In later years both Dr. Henry S. Pritchett, superintendent of the Coast Survey, and Frank A. Vanderlip, Assistant Secretary of the Treasury, claimed credit for bringing Stratton to Washington. Pritchett said that shortly after coming to the Coast Survey in 1897 he had—

> asked Congress to appropriate a salary sufficiently large to induce a physicist of high standing to take charge of the office, under direction of the superintendent. An appropriation of $3,000 was made. With this sum some difficulty was found in inducing any physicist of standing and reputation to accept the place, and only after many interviews and considerable correspondence I succeeded in persuad-

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[7] Natl. Acad. Sci., Biographical Memoirs, XVII, 254 (1935). See also personal letter, L. J. Briggs to Prof. E. Merritt, Cornell University, Oct. 31, 1933 (NBS Box 359, IG.).

[8] Letter, S. W. Stratton (hereafter SWS) to R. S. Woodward, president, NAS, Feb. 10, 1914 (Stratton Papers at MIT, Box 12; copy in NBS Historical File).

> ing Professor S. W. Stratton * * * to become a candidate. The appointment to the position was made after competitive examination.[9]

With this account Stratton agreed, in part at least:

> When I first came to Washington and met the Superintendent of the Survey, he asked me to join his force temporarily and make a report as to what could be done to place the weights and measures work upon the basis necessary in the present day of precision measurement of all kinds.

Although he at first declined the offer, Stratton said that on the train back to Chicago he made notes for a plan to revitalize the weights and measures work at the Coast Survey. Persuaded by his note-making, he gave up his planned trip to Europe and agreed to work in Washington during his sabbatical year.

In October 1899 he was formally appointed Inspector of Standard Weights and Measures and began preparation, says Stratton, of—

> two reports, one based upon the enlargement of that work [in the Survey office] to the extent possible in its present quarters, and dealing solely with weights and measures * * *. The other suggested the establishment of an institution having weights and measures functions in the broadest sense, covering measurements in the various lines of physics, the properties of materials and physical constants, etc. * * *.
>
> It was the Superintendent of the Coast and Geodetic Survey, Doctor Pritchett, who saw that the second plan was the preferable one. He recommended it to the Treasury Department, and the Secretary of the Treasury directed that a bill be drawn looking toward the establishment of such an institution.[10]

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[9] Pritchett, "The story of the establishment of the NBS," Science, 15, 281 (1902). This account also appears in letter, Pritchett to Dr. Wolff, Nov. 16, 1926 (NBS Blue Folder Box 4, APW–301c), and Abraham Flexner, Henry S. Pritchett: A Biography (New York: Columbia University Press, 1943).

[10] Stratton, "The Bureau of Standards and its relation to the U.S. C. & G.S." Centennial Celebration of the U.S. C. & G.S., April 5–6 1916 (Washington, D.C., 1916), p. 34. Stratton's reports, both dated Dec. 15, 1899, are in NBS Box 22, PRA. See also Science, 10, 941 (1899).

Stratton's civil service appointment as "Inspector of Standards" is dated Dec. 12, 1899 (Stratton Papers, Box 12). Another who took the examination for Inspector of Standards (in July 1899) was Charles S. Peirce, member of the Coast Survey from 1871–91, who had been in charge of weights and measures in 1884–85 and was then in his 60th year. Although strongly endorsed by Henry Cabot Lodge and others, Peirce was not considered, and later protested to Pritchett at the outcome of the inspectorship (communications from Dr. Max H. Fisch, University of Illinois, Sept. 13, 1962 and Mar. 23, 1965, at work on a biography of Peirce).

In his autobiography, written more than 30 years later, Frank Vanderlip recalled the event:

> In the Coast and Geodetic Survey there was a little sprout of an organization called the Bureau of Standards [sic]. Previously its function had been chiefly to serve as the depository of the nation's standards of weights and measures; although some other things were done there, the bureau was a puny affair. We wanted a new head for it and I found myself thinking of one who had been a close friend of mine at the University of Illinois, a boy named Sam Stratton. He had become a physicist, and at the University of Chicago Professor Stratton had come to rank next to Michelson, the measurer of light. On my recommendation the place was offered to Sam with the idea that he could develop the bureau into larger purposes. He was a thorough scientist with a great deal of imagination and not narrow in any part of him. It is satisfying even so many years afterward to realize that I had a hand in bringing such a valuable servant into the employ of the government. That Bureau of Standards grew to its present vast importance nourished chiefly in its growth by the intelligence of my old college friend.[11]

Vanderlip may have called him "Sam," but no one at the Bureau was ever to approach that degree of familiarity. As a full professor, even without his doctorate, he had the courtesy title of "Doctor," as was customary then. Later he was awarded six honorary doctorates, the doctor of engineering from Illinois and doctor of science from Pittsburgh in 1903, two more doctorates of science from Cambridge in 1908 and Yale in 1918; Harvard in 1923 gave him an LL.D., and Rensselaer in 1924 the Ph. D. At the Bureau he was "Dr. Stratton" to his friends and colleagues, or the "Old Man," among the frivolous youngsters on the staff, behind his back.

In appearance, Dr. Stratton at 40 was of medium height, mature, his sturdy frame and resonant voice commanding authority. He was a storehouse of specialized knowledge of industrial materials and mechanical devices of every sort and of the latest technical advances in physics and engineering. He delighted in constructing instruments and apparatus, and until his administrative duties became all consuming, maintained a private shop and laboratory near his office. Dr. Stratton never married, and he had as strong opinions about women in authority at the Bureau as in his home.[12]

[11] Frank A. Vanderlip, with Boyden Sparkes, From Farm Boy to Financier (New York: D. Appleton-Century, 1935), p. 77.

[12] He would not even accept women as clerks and secretaries at the Bureau until forced by the manpower shortage of World War I.

For over 20 years Samuel Stratton dominated the National Bureau of Standards, shaping it to serve the Nation and to hold its own or even surpass the national standards laboratories abroad. Like all good administrators, he recognized potential ability in young scientists he met or who applied to him. And as Kennelly says, he knew how "to organize them into cooperative effort for the purposes of applied science, without any consideration of his own personal advantage. His mind was dominated by the ideals of improving all engineering enterprise through scientific study and research." While it is true, as Kennelly implies, that his interest in technology was strong, Stratton knew that the Bureau must establish a solid basic research program and keep it at a high level if the Bureau was to fulfill its promise. Fundamental research was often difficult to justify to a cost-conscious Congress, but as he told a House committee in 1902, "If we are to advance we have to create original things." [13] More often than not he got his funds for basic research.

Stratton's office was to have its share of bureaucratic troubles, within the organization itself, with other government agencies, with members of the public, and with politicians. When differences arose, Dr. Stratton could be stern with the members of his staff—his flaming temper was famous—but he would defend them with all his might against the slightest interference or criticism that he believed unjustified. By its very nature, as impartial ruler and arbiter of standards, the Bureau could not escape controversy, but Stratton spoke with facts and a firm voice that kept controversy within bounds.

He never allowed anyone to forget that the Bureau's mission was to serve science and industry in the Nation, and he himself became filled with concern when a commercial chemist wrote of his difficulties with a product, an engineer with his materials, or an enquiring citizen sought technical help or information. He would scrawl in the margin of their letters: "Can't we do something about this?" "Why can't we do this?" "This deserves answering." But he was impatient with armchair inventors who thought the Bureau ought to construct working models for them from vague descriptions of vague ideas. Incoming mail at the Bureau, particularly in 1918, was freighted with suggested weapons and materials for winning the war, many of them, as Stratton said of a flux of letters proposing new alloys, "products which, although found excellent enough, are not in any way unusual, except in the secrecy about the composition which is observed by the inventor." [14] And he could be withering when a colleague was vilified for trying to let a crank down gently: "It is perfectly evident that you are more

[13] Hearings * * * 1904 (Dec. 4, 1902), p. 70.

[14] Letter, SWS to Dir, Bureau of Foreign and Domestic Commerce, Jan. 21, 1918 (NBS Box 11, IM).

The Coast and Geodetic Survey building, home of the Office of Weights and Measures, in the 200 block of New Jersey Avenue, S.E., as Dr. Stratton saw it in 1900. The Butler building, into which the new Bureau of Standards expanded, is probably the structure next door. "Bushey House," at 235 New Jersey Avenue, is out of the picture, down the street.

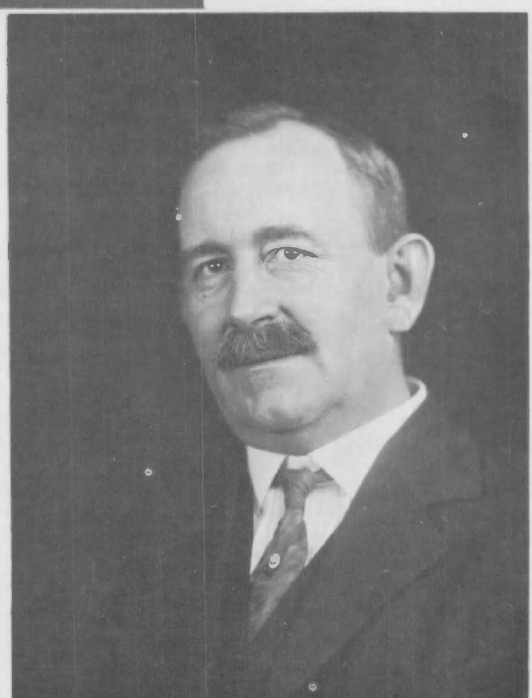
interested in giving information about a subject which, judging from your correspondence, you know little or nothing about, than you are in securing such information." [15]

But that was years later. When in the summer of 1899 Stratton arrived at the Office of Standard Weights and Measures, in the Coast and Geodetic Survey building at New Jersey Avenue and B Street, S.E., where the present House Office Building stands, its staff consisted of Andrew Braid, officially Assistant-in-Charge; Louis A. Fischer, adjuster of weights and measures; Dr. Frank A. Wolff, Jr., verifier of weights and measures (but then spending most of his time on problems of electrical measurement), and four others, a mechanician, an adjuster's helper, a messenger, and a watchman. On October 28, 1899, Stratton replaced Braid, with the temporary title of Inspector of Standards, at $3,000 per year.

Less than an hour was sufficient to tour the Office, see all its equipment, and comprehend its work. In Mr. Fischer's section "most of the apparatus * * * on hand [had been] designed many years ago." There was no "suitable instrument for the comparison of standards of length of

[15] Letter, SWS, Dec. 27, 1920 (NBS Box 14, IPR).

Mr. Louis A. Fischer, verifier of weights and measures, who came to the office in the Coast and Geodetic Survey in 1880 at the age of 16, when there were still men there who had worked with Hassler. This picture may have been taken shortly after the Bureau was founded, but no later than 1910, the year Mr. Fischer began his weights and measures crusade across the Nation.



Dr. Frank A. Wolff, Jr., who was able to certify standards of electromotive force but continued to send his other electrical measuring equipment to England and Germany for verification at the time this portrait was made.

1 metre or less," nor was the Office "prepared to make comparison of thermometers at temperatures lower than zero or higher than 50 degrees Centigrade." [16] Nevertheless, Fischer that year was to verify a number of thermometers, flasks, weights, and polariscopic apparatus used by the customs service in levying duties on imported sugar, adjust and verify the set of standards used in the State of Maine, and work on three sets of standards for States not yet supplied. He also prepared a set of metric standards for Puerto Rico, and graduated and verified 100-foot and 30-meter bench standards for the city surveyor of Boston, to be used in reverifying tapes and chains submitted to him.[17]

In the intervals free from pressing routine work, Dr. Wolff had set up a number of Clark standard cells for measuring standards of electromotive force and verifying direct-current voltmeters and millivoltmeters, had acquired equipment for testing resistance standards, and was at work on alternating-current testing apparatus, preparatory to answering some of the problems recently raised by long-distance transmission of power. But as Dr. Wolff said, "No claim to originality is made for what has been accomplished." The Office was still "obliged, as heretofore, to send to the national standardizing laboratories of Germany and England for verification [of] the large class of alternating current measuring instruments, condensers, and photometric standards." [18]

On June 30, 1900, the Office reported that in the past year it had compared 65 thermometers and 69 surveyors' tapes, had graduated and verified 772 sugar flasks, replied to 75 requests for information, and with routine weights, measures, and balance tests, had answered a total of 1,037 "calls" on it. Its appropriations amounted to $9,410.00, of which $8,237.44 was for salaries and $944.18 for contingent expenses.[19]

The law establishing the National Bureau of Standards, passed in March 1901, did not become effective until July 1, but within a week of its passage Stratton received his appointment as Director of the new Bureau from President McKinley.[20] During the interim 4 months he was to find a site for the new laboratory, plan its equipment, find the additional personnel

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[16] Annual Report, Coast and Geodetic Survey, 1899, p. 49.

[17] Annual Report, Secretary of the Treasury, 1900, p. lxviii.

[18] Annual Report, Coast and Geodetic Survey, 1900, p. 68; Annual Report, Secretary of the Treasury, 1900, p. lxviii. Also, Wolff, "The facilities afforded by the Office of Standard Weights and Measures for verification of electrical standards and electrical measuring apparatus," Sci. Am. Suppl. 49, 20304 (1900).

[19] Annual Report, Coast and Geodetic Survey, 1900, pp. 58-59, 69. Appropriations for 1899 had been $5,690 for salaries and $2,475 for expenses.

[20] The Presidents and executive secretaries under whom Bureau directors have served appear in app. D.

THE EVENING STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

A new bureau of the government, authorized by the last Congress, will be established in this city in the near future and will give employment to a number of persons. It is to be known as the national bureau of standards and is to be under the control of the Treasury Department. A separate building for a laboratory, to cost not to exceed $250,000, is to be erected on a site to be purchased at a cost of $25,000.

Mr. Samuel W. Stratton of Chicago has been appointed by the President to be chief of the bureau at an annual salary of $5,000. Prof. Stratton is to have the following as-

Director Stratton.

sistants, to be appointed by the Secretary of the Treasury: One physicist, at an annual salary of $3,500; one chemist, at $3,500; two assistant physicists or chemists, each at an annual salary of $2,200; one laboratory assistant, at $1,400; one laboratory assistant, at $1,200; one secretary, at $2,000; one clerk, at $1,200; one messenger, at $720; one en-

One of the first newspaper notices of the new Bureau in the Federal Establishment appeared in the Washington Evening Star. A half page feature in the Sunday Washington Times of August 23, 1903, included a picture of Secretary Cortelyou of the Department of Commerce and Labor laying the cornerstone of the main (South) building the day before, and described the ceremony as "a memorable event in the history of the country."

the Bureau would need, visit the more important laboratories here and abroad to see their construction, equipment, and the work they were doing, and set in motion, in the present Office, some of the more important lines of investigation to be pursued by the new Bureau.

It is not known in what order these tasks were taken up, but it seems probable that Stratton first secured additional laboratory space, in the Butler building, adjacent to the Coast Survey, hired a typist, which the Office had formerly lacked, and set the staff to work planning an expanded program. This included setting up an investigation of photometric measurements; developing means for testing high and low temperature instruments, clinical thermometers, and chemical glass measuring apparatus; developing electrical apparatus for measuring alternating currents, and equipment for testing pressure gauges and meteorological instruments.[21]

With his staff busy, Stratton may have begun visiting some of the larger Government laboratories in and near Washington, to see their work and learn what the Bureau might do for them. In April he sailed for Europe, to place orders for apparatus and equipment in Paris and Berlin, and to visit the International Bureau of Weights and Measures at Sèvres, the Reichsanstalt at Charlottenburg, the new National Physical Laboratory being organized at Teddington, and the Cavendish Laboratory at Cambridge.[22]

If the recent establishment of Britain's physical laboratory at Teddington helped prompt the creation of the National Bureau of Standards, the Reichsanstalt as the finest laboratory of its kind in the world was unquestionably to serve as the model for Stratton's organization of the Bureau. It seems probable that from the beginning Secretary Gage intended the Bureau to be a second Reichsanstalt. Early in 1899 he had corresponded with Henry S. Carhart, professor of physics at the University of Michigan, concerning American representation at the electrical congress to be held at the Paris Exposition in 1900. Further correspondence is missing, but it is possible that Gage was instrumental in sending Carhart to Berlin in the fall of 1899, where he secured permission to work at the Reichsanstalt as a scientific guest for several months. While there he "learned rather intimately the methods employed and the results accomplished in this famous institution for the conduct of physical research, the supply of standards, and the verification of instruments of precision for scientific and technical purposes." [23]

Carhart's detailed report on the organization and operation of the German institute, complete with architectural plans of the grounds and floor plans of the laboratories, was probably seen by Gage and Stratton before Carhart presented it as a paper to the American Institute of Electrical Engineers on September 26, 1900. It was published later that year in the Transactions of the Institute and also in Science magazine, and the next year

[21] Annual Report, Secretary of the Treasury, 1901, p. 59.

[22] Notice in Science, 13, 515 (1901). In September 1902, Stratton was again in Germany "studying the Reichsanstalt with a view to the buildings to be erected in Washington" (Science, 16, 437, 1902).

[23] Carhart, "The Imperial Physico-Technical Institution in Charlottenburg," Report of the Committee on Commerce, to accompany S. 4680 (1901), p. 6 (L/C:QC100.U58-1901b).

The first description, in English, of this institution appeared in Arthur G. Webster's article, "A national physical laboratory," The Pedagogical Seminary (Worcester, Mass.), II, 90-101 (1892). The article, Webster later recalled (Science, 56, 170, 1922), had been refused by a number of scientific periodicals, their editors rejecting his plea for a similar laboratory in this country as an improper function of the Federal Government.

appeared as an appendix to a congressional report of the Committee on Commerce, in the Annual Report of the Smithsonian Institution for 1901, in the Western Electrician, and, for a seventh time, in the London Electrical Review. There seems little doubt that the report was regarded as a blueprint.

With modifications, the Bureau was to organize its work, like the Reichsanstalt, in two spheres, scientific and technical, including "a division for pure scientific research, mechanical measurements of precision, electrical measurements and instruments, the measurement of large direct and alternating currents and electromotive forces, an optical department, a department of thermometry, a department of pyrometry, and a department of chemistry. To these as auxiliaries should be added the power plant and the workshop." [24] Their re-creation in Washington was only a matter of time.

On his return from abroad, Stratton met with Lyman Gage to recommend members for the Secretary's Visiting Committee, a liaison group composed of prominent men of science and industry who were to keep Gage informed of such national interests as were within the Bureau's domain, and report annually to the Secretary on the work of the Bureau. Thoughtfully, Stratton suggested his former superior at Chicago, Professor Michelson, for membership on the Committee. Although Michelson was greatly interested in standards, had worked at the Bureau International des Poids et Mésures in 1892–93, and served on the International Committee of Weights and Measures since 1897, he declined the invitation.[25] Letters were then sent by Gage to Albert Ladd Colby, chief metallurgical engineer at Bethlehem Steel and secretary of the Association of American Steel Manufacturers, as representative of manufacturing interests in the country; to Dr. Elihu Thomson, chief electrical engineer at General Electric, who held almost 500 patents for electrical inventions and improvements, and would represent electrical interests; to Dr. Ira Remsen, professor of chemistry and president of the Johns Hopkins University, representing chemical interests; to Dr. Henry S. Pritchett, now president of the Massachusetts Institute of Technology, representing technical education institutions; and to Dr. Edward L. Nichols, professor of physics at Cornell University, as representative of physical interests.[26]

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[24] Ibid., p. 7.

[25] While at the International Bureau, Michelson with a new interferometer he had designed carried out a pioneer study in standards measurement, relating the cadmium red line to the meter, the first significant beginning of a wavelength definition of the meter.

[26] Letter, Gage to Michelson, June 6, 1901, and letters, June 18, 1901 (Correspondence of the Secretary of the Treasury, 1900–1901, V series, vol. 6, NARG 56). A complete list of members of the Visiting Committee to the NBS from 1901 to 1960 appears in app. E.

Little is known of the Visiting Committee's assistance to Dr. Stratton in the early months of the Bureau except that it met for the first time in the summer of 1901 "to pass on proposed sites for the laboratory."[27] Stratton had already toured the Washington area looking at possible sites and had tentatively settled on a location out on Connecticut Avenue, almost 3½ miles from the White House and within 2 miles of Chevy Chase, Md. Just inside the site of the line of forts built to the North to protect the city during the Civil War, the heavily wooded height comprising nearly 8 acres rose more than 75 feet, the highest ground in the vicinity, overlooking Connecticut Avenue. A laboratory up there would be well away from the street noise and interference from the electric cars running out Connecticut Avenue to Chevy Chase.

The site, "one of the most beautiful in the District of Columbia," Stratton thought, was for sale, and its owner, the Chevy Chase Land Co., was persuaded to let it go for $25,000, the sum available.[28]

By July 1, 1901, when with minor ceremonies the old Office of Standard Weights and Measures became the new National Bureau of Standards, two contracts had been let. One was for a mechanical laboratory, to house the power and service plant and shops of the main laboratory, scheduled to be completed by July 1902. The second, for the physical laboratory itself, was to be completed by January 1903. That same day, July 1st, Dr. Edward B. Rosa arrived at the Bureau.

EDWARD B. ROSA

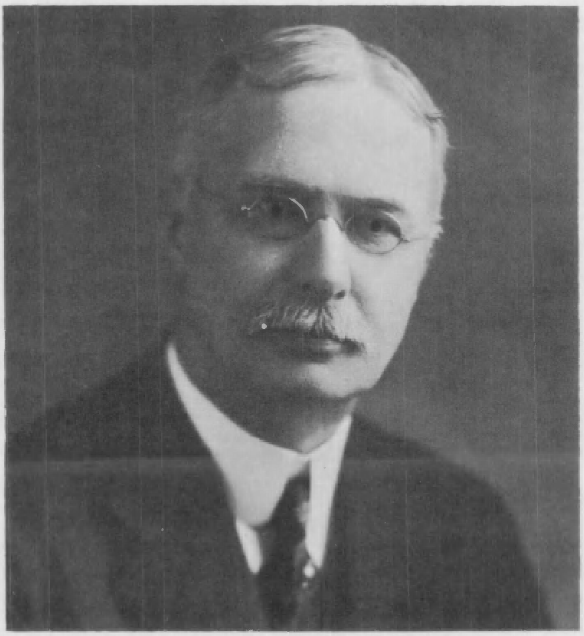
Dr. Stratton's most pressing need upon his appointment as Director of the Bureau was to find an outstanding man to plan and direct the electrical research that had dominated the arguments for the creation of the Bureau. Demands for routine electrical testing now took all of Dr. Wolff's time, and original research or even planning such research was out of the question.

Stratton's attention was drawn to a professor of physics at Wesleyan University who in the past decade had published a dozen papers on electricity. With Prof. Wilbur O. Atwater, he had recently devised an ingenious respiration calorimeter that was to prove highly useful in subsequent pioneer investigations of food values and problems of nutrition in this country.[29] His

[27] Notice in Science, 14, 340 (1901); Visiting Committee correspondence, 1902, in "General Correspondence Files of the Director, 1945-55," Box 6 (in process in NBS Records Management Office for NARG 167) (see Bibliographic Note).

[28] NBS Annual Report 1905, p. 4; Remarks of SWS at the laying of the cornerstone of the Chemical Laboratory, March 23, 1916 (NBS Historical File); Remarks of SWS on the 30th Anniversary of the NBS, March 7, 1931 (Stratton Papers, Box 12).

[29] See Atwater and Rosa, "A new respirator calorimeter * * *," Phys. Rev. 9, 129, 214 (1899), and the special notice of it in William North Rice's article, "Scientific thought in the nineteenth century," Annual Report, Smithsonian Institution, 1899, p. 399.



Dr. Edward B. Rosa, who set the pace for the high level of research at the Bureau in its first two decades. Rosa probably sat for this portrait about 1915, but according to Dr. Silsbee, who knew him, it could have been made at almost any time, for Dr. Rosa did not change much in all his years at the Bureau.

name was Rosa (pronounced Ro-zay), and meeting him, Stratton knew he was the man he sought.

Edward Bennett Rosa (1861–1921), of Dutch ancestry, had taught physics and chemistry after getting his B.S. degree at Wesleyan University in Connecticut and then entered the Johns Hopkins University as a graduate student in physics under Henry A. Rowland. Receiving his doctorate in 1891, he returned to Wesleyan as associate professor of physics, becoming full professor the next year. He came to the Bureau as a physicist at $3,500 and a decade later, his electrical group firmly established as the premier division of the Bureau, he was made chief physicist.

Like Stratton, Rosa was of distinguished appearance. He was not as outgoing in temperament as the Director, yet he made a strong impression on scientific and administrative visitors to the Bureau and before long became its stellar ambassador at home and abroad. If Stratton was the autocratic paterfamilias of the Bureau, interested in every laboratory and its occupants and the source of intense staff loyalties, it was Rosa, the autocrat of research, who set the pace for the high level of achievement in the early years of the Bureau. The names of Stratton and Rosa are inseparable in any consideration of the period.

It is a tribute to Rosa's character, as those with long memories recall, that his own forceful personality rarely clashed with that of Stratton. The Director fully agreed with Rosa's concept of the importance of the electrical work of the Bureau and saw that he had the best of equipment and the best of assistance to conduct his program. Where the Bureau was concerned, they acted as one, and during Stratton's frequent absences on official business, Rosa's decisions were final.

A diligent investigator—he published over 75 papers while at the Bureau—Rosa demanded the same industry from his staff. But while their minds were kept firmly on electrical matters, his increasing administrative responsibilities, as well as his peripheral interests and zest for public affairs, drew him repeatedly out of the laboratory. Unlike Stratton, he enjoyed talking to groups of people and gave many lectures, later published, on the work of the Bureau, the progress of electrical research, and the range of scientific work being done in the Government. His most ambitious effort late in his career was an exhaustive study of Government research and its relation to the Federal budget, which was to lead indirectly to the establishment of the present Bureau of the Budget.

It was said of Dr. Stratton that he was "continually on the lookout for worthy research and testing work, and so the staff always seemed overburdened."[30] It was equally true of Rosa, who followed closely each new development in the field of electricity, saw research projects everywhere, and brought in a stream of bright young men to investigate them.

In its early years the Bureau regularly hired young men who were potential specialists in their fields, only to win them to the ever-increasing range of interests spanned by the Bureau. Before midcentury the advance of science would demand many at the Bureau working at the extremity of specialization. But Dr. Rosa, with wide interests himself, was wary of the possible narrowing influence of high specialization—that should be left to the universities, he said—and warned his division of its inevitable consequences, that "we grow taller and thinner."[31] The justification for the Bureau's ranging research was the clause in its enabling act making it responsible for the "solution of problems which arise in connection with standards." Since almost every aspect of science, technology, industry, and commerce is rooted in standards of some kind, all knowledge in these fields was by definition within the Bureau's province. So Stratton, who had written the clause, interpreted it, and under the guidance of Stratton and Rosa, the Bureau acted upon it.[32]

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[30] Fay C. Brown, "Samuel Wesley Stratton," Science, 74, 428 (1931).

[31] W. W. Coblentz, "Edward Bennett Rosa," Natl. Acad. Sci., Biographical Memoirs, xvi, 356 (1934).

[32] Years later Stratton was to say that he thought an enumeration of the organic functions of the Bureau covered "about 99 percent of the field of research." Only food, drugs, and materia medica were exempt. SWS address on the 25th anniversary of the NBS, 1926 (Stratton Papers).

Free exercise of the clause, as we shall see, enabled the Bureau to conduct an abundance of original research, some of it only vaguely connected with standards. At the same time, it subjected the Bureau to a plethora of investigations for Federal agencies and the public that at times tended more to dissipate its energies than to increase its knowledge. The legacy of accommodation left by Stratton and Rosa created occasional difficulties in later years. Periodically, as its investigations became too far ranging, the Bureau found it necessary to stop, reassess its scope and functions, and shift course. But it never lost sight of its primary responsibility, and the whole focus of its early research, the pursuit of standards.

During the 3½ years in its temporary quarters in downtown Washington, the Bureau was completely taken up with planning new work on standards, searching for personnel, acquiring or designing new equipment, and overseeing the construction of its new laboratories. In September 1901 Henry D. Hubbard, who had been private secretary to President Harper at the University of Chicago, came as secretary to the Bureau, his desk in Dr. Stratton's office in the Butler building. He was to serve the Bureau for almost four decades.[33] That same month Dr. Charles W. Waidner, a young physics instructor trained at Johns Hopkins, who had taught there and at Williams College, arrived to organize the Bureau program in heat and thermometry. In the laboratories over in the Coast Survey building, Rosa, Wolff, and their assistants continued to acquire equipment and carried out electrical tests, while Fischer, with his new assistant, Roy Y. Ferner, looked after the weights and measures work.

Orienting a growing staff and organizing its work permitted little forward motion. One new member was later to say that while he did some testing of instruments, the major part of his time in his first year at the Bureau "was spent in library work. * * * Only the functions of the old Office of Standard Weights and Measures were operating normally." [34] In December 1901 Dr. Stratton announced in Science, apparently in answer to inquiries, that the range of Bureau services was as yet limited. More exact determination of values for certain of the fundamental electrical constants, better photometric measurements, and calibration services such as those requested for clinical thermometers, pressure gages, and many other instruments, while urgently needed, were simply not yet possible. For the time being the work of the Bureau was confined to the comparison of a few standards and measuring instruments, that is, to length, weight, and capacity

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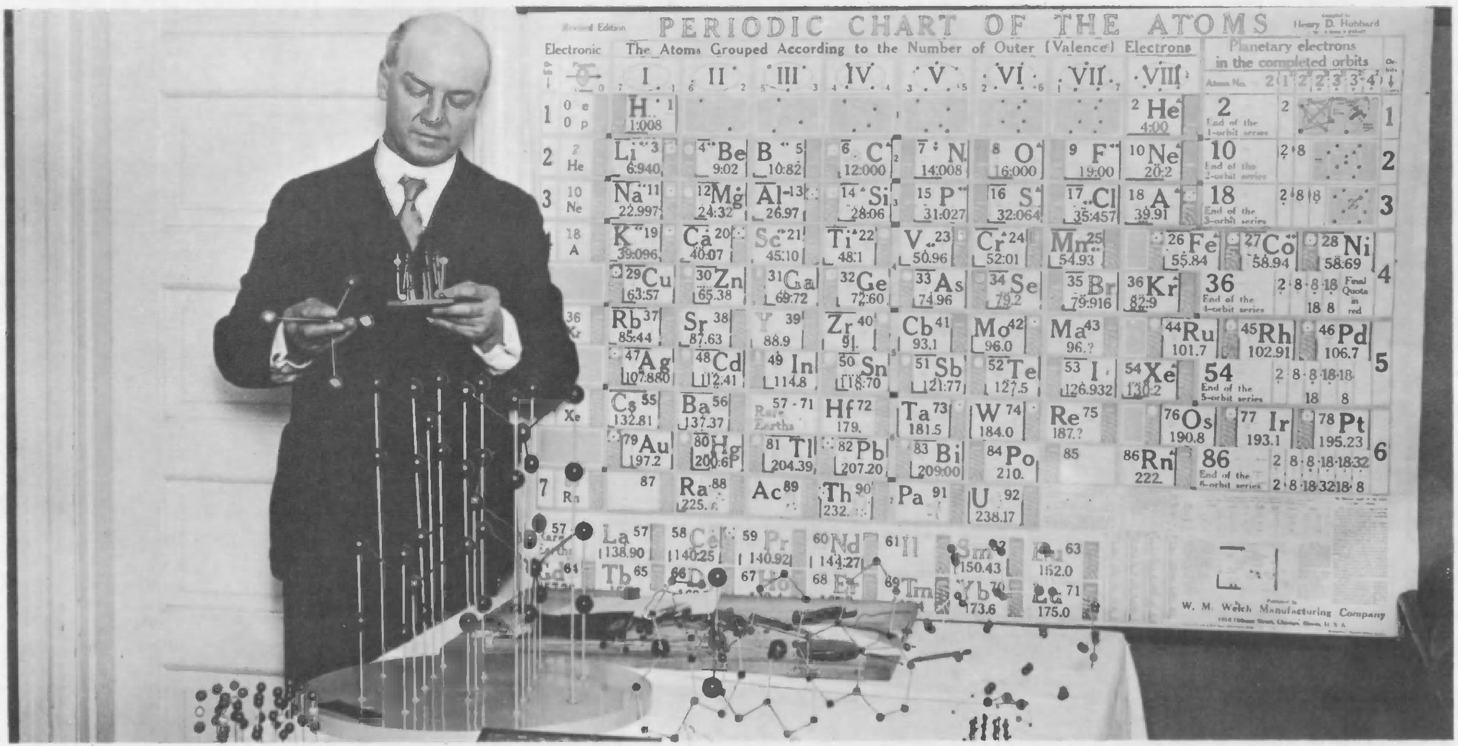
[33] A contribution to scientific literature, Hubbard's modernization of Mendeleev's periodic table of the elements, first printed in 1924, is currently published by the Welch Scientific Co. of Skokie, Ill.

[34] MS, N. Ernest Dorsey, "Some memories of the early days of the NBS," Oct. 28. 1943 (NBS Historical File).



Henry D. Hubbard, secretary to Dr. Stratton and the Bureau, made a contribution to instruction in physics that is still in use today, his modernization of Mendeleev's periodic chart of the atoms. First constructed in the 1920's, it has been frequently revised and reprinted. It now includes the isotopes of the elements, unknown to the twenties.

Dr. Charles W. Waidner, a decade after he came to the Bureau, who with Dr. Burgess in the heat and thermometry division attempted to construct an absolute standard of light, not to be experimentally realized until 1931, 20 years later.

measurements, testing of ordinary commercial thermometers, polariscopic apparatus, hydrometers, resistance instruments, standards of electromotive force, and direct current apparatus.[35]

By July 1902 the original staff of 12 had increased to 22, and the 15 offices and laboratories of the Bureau were crammed with crated and uncrated apparatus and machinery. To get elbow room, Stratton rented a four-story house at 235 New Jersey Avenue, not far from the Coast Survey building, converting its space into an instrument shop, dynamo, and storage battery rooms, and additional laboratories. Approximately equivalent only in their antiquity, the high, narrow residence at 235 was promptly christened "Bushey House," after the stately mansion in England that had recently become the home of the National Physical Laboratory. Much of the new apparatus was moved there to be set up and tested, while on the upper floors preliminary studies began in alternating current measurement and in pyrometry.[36]

During the summer of 1902 Wolff and Waidner went abroad to visit the principal government laboratories and instrument makers in Europe, taking with them a number of electrical and pyrometric standards to verify while in Berlin. The next summer Fischer visited Paris with his copies of

[35] Stratton, "Circular of information on the NBS, No. 1," Science, 14, 1019 (1901).

[36] MS, Dorsey, "Some memories of the early days"; NBS Annual Report 1902, pp. 4–5.

the international meter and kilogram, but like Wolff and Waidner he spent most of his time in Germany, securing new instruments and apparatus and ordering equipment for the laboratories under construction at home. In Washington a change of departmental administration was in the making that was to have important consequences for the development of the Bureau.

THE NEW BUREAU LABORATORIES

Dr. Stratton and his staff were still in downtown Washington when the Bureau was transferred from its original home in the Treasury Department to the newly created Department of Commerce and Labor. For more than a hundred years the head of the Treasury had been in fact "secretary of commerce and finance," but with increasing fiscal responsibilities and the growth of agencies required by the commercial expansion of the Nation, his Department had become unwieldy. In December 1901 a bill was introduced in the Senate to transfer some of his functions to a separate Department of Commerce.

The Commissioner of Labor (first appointed in 1888) was seeking cabinet rank at the time, but loath to expand the President's Cabinet by two, Congress compromised by merging a number of bureaus in the Departments of the Treasury and Interior with those in the Office of the Commissioner of Labor. On February 14, 1903, the new Department of Commerce and Labor came into being, its Secretary, George B. Cortelyou.[37]

With 13 subdivisions, the new Department was at once one of the largest and most complicated branches in the Federal Government. Curiously enough, the transfer of the Bureau of Standards to Commerce and Labor was an 11th-hour decision. Like the Coast and Geodetic Survey, whose transfer had occasioned some discussion before it was included in the new Department, the Bureau was apparently considered by Congress to be a purely scientific agency, with only a remote relation to commerce.

A member of the House Committee on Interstate and Foreign Commerce, aware late in the proceedings that the Bureau was likely to be left out, rose to urge its transfer: "The newly created National Bureau of Standards is a bureau which necessarily goes into a department primarily devoted to manufacturing and commercial interests. This Bureau is destined to

[37] Organization and Law of the Department of Commerce and Labor, Doc. No. 13 (Washington, D.C., 1904), pp. 7, 12, 450.

A genius of managerial efficiency, Cortelyou had been stenographer to Cleveland, assistant secretary to McKinley, and secretary to Roosevelt before his appointment to the new Department. Two years later he was appointed Postmaster General, and in 1907 became Secretary of the Treasury. In 1909 he left Government service to head the Consolidated Gas Co. in New York.

exercise great influence upon the development of business and commerce of our country." Commerce and Labor was already outsize, but the Bureau was voted in.[38]

Had it remained in the Treasury, the Bureau might well have become a giant in precision measurement alone, its research almost certainly more narrowly confined to the functions of its enabling act. But under a succession of strong Secretaries of Commerce, vigorously promoting business and industry, the Bureau was to be used unsparingly to introduce scientific methods more rapidly in industry, to urge the standardization of parts and products, and the use of new and improved materials, and even do the spadework to encourage the manufacture of products previously imported. The wonder is that the Bureau accomplished as much basic research as it did in the years that followed.

Except for the change of name to "Bureau of Standards," omitting the word "National," the transfer to the new Department was without incident. Relations between the new Secretary and "Prof. S. W. Stratton," as Cortelyou addressed him in correspondence, were cordial, and Cortelyou willingly approved a Bureau request for an increase in its staff from 28, authorized by a previous appropriation act, to 58, authorized on February 25, 1903.[39]

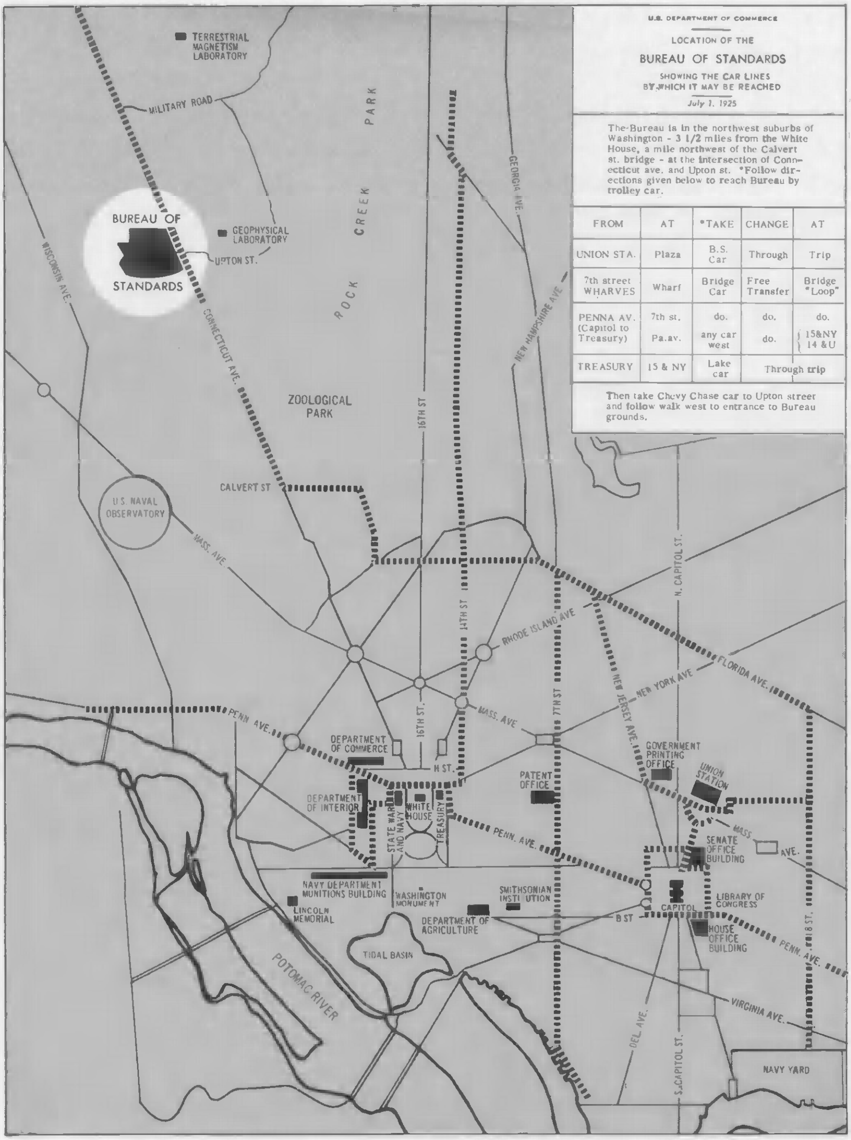
Finding room for the growing staff in the downtown quarters of the Bureau was another thing. Construction of both buildings out on Connecticut Avenue was behind schedule. The smaller mechanical laboratory, well under way, was now promised for September of 1903, but work on the main building, the physical laboratory, had just begun that March. It would not be ready for occupancy before October 1904, almost 2 years later than originally planned.

Some of the delay was understandable, for the site was distant and transportation of materials was slow. The teams of horses under their heavy loads had to rest frequently on the long grade uptown and more often still as they struggled up the steep of Pierce Mill Road, the dirt track through the woods to the top of the hill. Four- and eight-horse teams were frequently needed to haul building materials up the height, and it is possible that some of the big equipment for the mechanical building may even have required a 16-horse hitch.

The Bureau site was, for that time, truly remote. In the 2½ mile stretch of Connecticut Avenue between Cleveland Park, then a sparse residential section to the north of the business center of Washington, and Chevy

[38] James R. Mann (Ill.), Chairman of the Committee, Jan. 30, 1902, quoted in Organization and Law of the Department of Commerce and Labor, pp. 529, 539.

[39] Ibid., pp. 415–417, 417n. Graphs and charts of congressional appropriations and other working funds of the Bureau, of special appropriations, of the rise in the Bureau staff, and its output of publications appear in apps. F, G, H, and I.



The remoteness of the Bureau made it necessary to send vest-pocket transit maps to early visitors to show them the way out. When they arrived they were to look for the boardwalk that led up the hill to the Bureau grounds, since the first buildings were invisible from Connecticut Avenue.

Chase, the small Maryland community on the border of the District of Columbia, there were but two buildings, occupied by a preparatory school. The Bureau up on the hill was invisible from the avenue, and these lone school buildings, just north of what is now Upton Street, served to show staffers and strangers alike on the way to the laboratories where to leave the electric cars.[40]

The mechanical building was above ground but excavation for the physical laboratory had not begun when Dr. Rosa, with the architect's plans before him, described for Science magazine the Bureau plant as it would appear when completed. Both buildings were to be constructed of dark red brick with Indiana limestone trim, the smaller mechanical laboratory two stories tall but with its basement at ground level on the north slope of the hill. The physical laboratory, four stories tall, would be supported solidly on concrete piers in a largely unexcavated basement.

Since the principal experimental work of the Bureau was to be carried on in the physical laboratory, later called South building, it had to be free from mechanical and magnetic disturbances and therefore housed scarcely any machinery. All heavy equipment was located in the mechanical laboratory or North building, its basement and partial sub-basement containing the boiler room, engine and dynamo room, storage battery room, and a refrigeration plant with a capacity equivalent to melting 30 tons of ice a day, phenomenal for that time. Through a spacious tunnel 170 feet long leading out of North building's sub-basement, a maze of air ducts, steam, gas, and water pipes, and electrical circuits supplied the major facilities of the laboratories in South building.

On the first floor of North building were the heavy current and alternating-current instrument testing laboratories, the instrument shop, and stock and shipping rooms. High potential laboratories and magnetic and photometric laboratories occupied the second floor, with a proposed hydraulic laboratory on that floor extending through the ceiling into the attic. Another photometric laboratory and storage rooms occupied the other half of the attic. With its heating and ventilating plants, machinery, and special facilities, North building was to cost $125,000. Additional laboratory space was created in 1931 when the roof was raised and a third story added to the building.[41]

In the huge physical building, facing south overlooking the city of Washington, all the laboratories were to be provided with gas, compressed air, vacuum, hot and cold water, ice water, and distilled water. All windows

[40] MS, Dorsey, "Some memories of the early days."

[41] Ostensibly added to make North building conform architecturally with the other buildings in the quadrangle. NBS Annual Report 1928, p. 42.

in the first and second floor laboratories were double-paned and sealed tight, and each room could be darkened completely. Filtered air, artificially cooled in summer, circulated in the building, and each laboratory was equipped with controls to regulate room temperature and humidity precisely. Special facilities available in certain of the laboratories included cold brine, carbon dioxide, and liquid air for low temperature work; gas and electric furnaces for high temperature studies; direct electric currents at potentials up to 20,000 volts and currents up to 20,000 amperes.

Weights and measures, optical research, high and low temperature laboratories, and electrical standards laboratories occupied the ground floor. On the second floor were additional weights, measures, and optical laboratories, the inductance and capacity laboratories, and electrical measurements rooms. The director's office, a reception room, the library, a publication and mailing room, and Dr. Stratton's private laboratory occupied the third floor, and on the fourth were to be the thermometer laboratories. A large lecture room (subsequently diverted to storage) and apparatus space utilized the attic. With its connecting tunnel, but exclusive of equipment, South building cost $200,000.

In this initial complex, based on Bureau specifications and designed by the Supervising Architect of the Treasury Department, said Rosa, the Bureau intended "an intimate association between research and testing in the domain of physics, extending into the field of chemistry on the one hand, of engineering on the other." [42]

The program of work then planned by no means utilized all the laboratories provided in the two buildings. But Congress had said that the building appropriations must cover the first 5 years of the Bureau, and it took little imagination to see that as its resources and range of skills were recognized, the demands on the Bureau would increase. Even then Stratton and Rosa foresaw the necessity of East and West buildings, to complete the quadrangle, although their purpose, except to provide additional laboratory space, was not yet plain.

Startlingly plain, once spotted, however, was something entirely omitted in the original architectural plans of the two buildings. There was no place to eat. The "thermometer and photometric standards laboratories" on the fourth floor of South building had to give way to a council lunch room (later the senior lunch room) and a junior lunch room, with a kitchen between. By the time the staff moved in, these were equipped with tables

[42] Rosa, "Plans for the new buildings for the NBS," Science, 17, 129 (1903). For later modifications in the interior planning and details of facilities and equipment, all more or less minor, see Stratton and Rosa, "The National Bureau of Standards," Proc. AIEE, 24, 1039 (1905).

made in the Bureau workshop and furnished with chairs, dishes, and kitchen equipment carted out from the city. Discussions about providing a more expensive lunch for the seniors and a less expensive one for the juniors foundered on the single kitchen they shared, and the staff was not yet large enough to afford a cafeteria. It became the great insoluble problem of the first decade.[43]

But that problem was not in sight when, during the winter of 1903–4, the instrument shop downtown was moved out to the North building and its great dynamos, motor generators, refrigeration plant, storage batteries, gas-making machine, air compressor and other apparatus were installed. In the spring, Dr. Rosa and his group, bringing their lunches with them each day, moved into North building as the remainder of the staff spread out in the vacated rooms downtown.

ACQUIRING NATIONAL STANDARDS

No one knew better than Dr. Stratton that the Bureau had started from scratch and that for a long time it would have nothing spectacular or even noteworthy to show for its efforts. The Bureau would have to live on borrowed time, borrowed standards, and borrowed instruments while it acquired the materials and methodology for research. Members of the Bureau visiting abroad had found the standards laboratories of France, Germany, and England openhanded, the instrument-makers of those countries helpful in the extreme, and they came home laden with the best equipment and knowledge of standards then available.

At the end of its third year the Bureau had achieved a sense of unity and purpose, and sufficient personnel to do something more than make comparison of a limited number of standards. It was ready, as Rosa said, to "do in its field what the Coast Survey and the Geological Survey and the Department of Agriculture are doing in theirs." [44] It had acquired almost $225,000 worth of apparatus and equipment, much of it abroad, some bought from instrument-makers and manufacturers in this country, and not a little constructed in its own shops. Two of the three divisions were well advanced in their organization (see below), although with the limited staff Dr. Stratton not only directed the Bureau but was in personal charge of a division and of one of its sections, while Dr. Rosa in his division also supervised two of its sections. For the first time it was possible to see just what had been ac-

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[43] MS, Dorsey, "Some memories of the early days."

[44] Rosa, "The organization and work of the Bureau of Standards," Science, 19, 937 (1904). Much of the material of this chapter is based on this article.

complished, what the Bureau was prepared to do, and what were the immediate tasks before it.

The Staff of the Bureau of Standards, June 24, 1904 [1]

Director—Dr. Samuel W. Stratton (University of Illinois, University of Chicago)

Division I—Dr. Samuel W. Stratton

1. Weights and measures:
   - Louis A. Fischer (Columbia University)
   - Llewelyn G. Hoxton (University of Virginia)
   - Roy Y. Ferner (University of Wisconsin)
   - Nathan S. Osborne (Michigan School of Mines)
   - Lloyd L. Smith
2. Heat and thermometry:
   - Dr. Charles W. Waidner (Johns Hopkins University)
   - Dr. George K. Burgess (MIT, University of Paris)
   - Dr. Hobart C. Dickinson (Williams College, Clark University)
3. Light and optical instruments:
   - Dr. Samuel W. Stratton
   - Dr. Perley G. Nutting (University of California, Cornell University)
   - Dr. Frederick J. Bates (University of Nebraska)
4. Engineering instruments: Albert S. Merrill (MIT)
5. Office: Henry D. Hubbard
6. Instrument shop: Oscar G. Lange

Division II (Electricity)—Dr. Edward B. Rosa (Wesleyan University)

1. Resistance and Emf:
   - Dr. Frank A. Wolff, Jr. (Johns Hopkins University)
   - Francis E. Cady (MIT)
   - Dr. George W. Middlekauf (Johns Hopkins University)
2. Magnetism and absolute measurement of current: Dr. Karl E. Guthe, (University of Marburg, University of Michigan)
3. Inductance and capacity:
   - Dr. Edward B. Rosa
   - Dr. N. Ernest Dorsey (Johns Hopkins University)
   - Frederick W. Grover (MIT, Wesleyan University)
4. Electrical measuring instruments:
   - Dr. Edward B. Rosa
   - Dr. Morton G. Lloyd (University of Pennsylvania)
   - Herbert B. Brooks (Ohio State University)
   - C. E. Reid (Purdue University)
   - Franklin S. Durston (Wesleyan University)
5. Photometry: Edward P. Hyde (Johns Hopkins University)
6. Engineering plant: Charles E. Sponsler (Pennsylvania State College)

[1] Source: Science, 19, 937 (1904). Details of the education and experience of the original Bureau staff and a résumé of current activities appear in Report of the Dir, NBS, to the Visiting Committee, June 12, 1903 ("Gen Corresp Files of the Director, 1945–1955," Box 6).

Charts of the organization of the Bureau and its supervising personnel, at 5-year intervals from 1901 to 1960, appear in app. J.

Division III (Chemistry)—Dr. William A. Noyes (Johns Hopkins University)
Dr. Henry N. Stokes (Johns Hopkins University)

[Additional personnel included 1 librarian, 1 computer, 1 draftsman, 4 clerks, 2 messengers, 1 storekeeper, 4 mechanicians, 2 woodworkers, 3 apprentices, 2 laborers, 1 assistant engineer, 1 electrician, 2 firemen, 2 watchmen, 1 janitor, 1 charwoman—a total of 58 at the Bureau.]

But first a word about the hierarchy of standards with which the Bureau was, as it still is, concerned.[45] At the apex are the *prototype standards,* those of length, now defined in terms of the red radiation from krypton 86, and mass, the platinum-iridium kilogram cylinder maintained by the International Bureau of Weights and Measures at Sèvres; and of time and temperature, based on the revolution of the earth around the sun and the freezing and boiling points of water (now, the triple point of water).[46] These are the standards which, with certain defining relationships, fix the size of all units in a measuring system and are absolute in the sense that they do not depend on any other standards.

National standards are those which fix the prototype or international value on a national basis, as in the instance of the copies of the prototype meter and kilogram maintained at the Bureau; or are derived standards, such as the standards of frequency, volume, or electricity, depending by definition upon natural or material standards of the prototype category.[47] Thus until the establishment of the absolute ohm in 1948, the ohm was defined by an act of Congress of 1894 as "the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area, and of the length of 106.3 cm." [48]

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[45] The nomenclature for standards of measurement has itself never been entirely standardized. What are called prototype standards are also known as international standards. Primary (now, reference) standards were those either maintained at the PTR or constructed as such by the Bureau and intercompared with the standards abroad. Secondary and working (now, derived and calibration) standards were lower orders of primary standards.

The hierarchy of standards described here is largely based on A. G. McNish, "Classification and nomenclature for standards of measurement," IRE Trans. Instru. 1–7, 371 (1958), and "Measurement standards report," ISA J., February 1961, pp. 1–40.

[46] As the standard of length, long based, as Stratton knew it, on the international meter bar at Sèvres, gave way to the wavelength of krypton 86 light, with superior standards possible in mercury 198 and later sources, so the standard of time, long based on the ephemeris second, is now provisionally based on the resonance frequency of the cesium atoms in the atomic clock. See ch. VIII, pp. 462–463, 477.

[47] See flow chart in NBS C531 (1952), p. 2, for the Bureau's experimental establishment of the eletrical units by absolute measurement.

[48] For the absolute ohm, see ch. VI, p. 337.

Since national standards, whether definitions or materials made of precious metal or of delicate construction and necessarily preserved under special conditions, may be impractical, or frequent use may impair their accuracy, the Bureau maintains *national reference standards,* often of its own construction, the values of which are derived directly from the national standards, but of suitable material or form for more frequent service.

Next are the *working* or *calibration standards,* those which are ordinarily used in calibration and which are themselves calibrated in terms of the corresponding reference standards. They are compared as frequently as necessary with the reference standards and sometimes even with the national standards.

In most instances it is the Bureau's reference or calibration standards that are the immediate source of industrial and commercial standards and of the precision measurements of science. Against these are calibrated the *laboratory reference standards* of science and industry. Whether a precision thermometer, a kilowatt hour meter, or a standard of length, weight, or mass, it is brought to the Bureau periodically and carefully calibrated against the Bureau's reference standard. Returned to the factory or plant, the laboratory reference standard then becomes the basis for calibration and adjustment of the *laboratory working standards,* by which shop instruments and measuring apparatus in daily use by technicians and inspectors are calibrated.[49]

This sequence of standards is of course meaningless without special comparison equipment—longitudinal and geodetic comparators for length standards, the balances used in comparing masses or weights, the potentiometers, bridges, and consoles used in electrical measurements—by means of which all standards of a given type are intercompared in order to determine the order of agreement among them. Differences naturally exist between the nominal value of any standard (except a prototype) and the value it is found to have when compared with a known standard, by reason of differences in their composition or construction, circumstances of measurement, or other irreducible factors, but the discrepancy as an observable quantity, can be adjusted or compensated for, or even within certain limits may be accepted as a permissible tolerance.

In the relatively uncomplicated world of 1904, scientifically speaking, American industry had need for stability and accuracy of measurement rather than high precision. Industry had little requirement as yet for working measurements closer than a thousandth of an inch, but to achieve that with a milling machine, for example, the accuracy of the company master standard had to be on the order of a ten-thousandth of an inch, the Bureau's

[49] For the operation of laboratory standards, see NBS C578, "Suggested practices for electrical standardizing laboratories" (1956), p. 1.

reference standard a hundred-thousandth of an inch, and its primary standard a millionth of an inch.[50] A time would come when industry would have need for that millionth of an inch, and science for the ten-millionth. Continual research looking toward more precise standards, instruments, and techniques was to narrow the gap everywhere in the hierarchy of standards.

Apart from length and mass and certain electrical units, few standards were inherited by the Bureau from the old Office of Weights and Measures. The major part of the Bureau's activities in its early years was thus spent in establishing the discipline of standards for this country, such as other nations already possessed, and obtaining or making the measuring apparatus and instruments to carry out the calibrations required by science and industry. Besides new measurements of length and mass, there was need for new standards of electrical quantities, standards of heat and temperature, of light and radiant energy, density and pressure, and even new values for the factor of gravity. Only the most immediate of these had been accomplished by 1904. Not all of them were wholly satisfactory as yet but an impressive beginning had been made.

In the *weights and measures* section (see above), soon to become an independent division, as were the heat, optical, and engineering groups, the Bureau had the two platinum-iridium copies of the international meter bar, to which all length measurements, both customary and metric, were reduced. Fischer had taken one of the platinum-iridium bars to Paris the previous year and with new apparatus acquired there recompared it with that at the International Bureau of Weights and Measures at Sèvres and found it satisfactory.

The Bureau was now prepared to determine any standard of length from 1 decimeter to 50 meters, to calibrate the subdivisions of such standards, and to determine their coefficients of expansion, that is, the slight changes in dimensions when in use at ordinary ranges of temperature. Working standards derived from the Bureau's two platinum-iridium copies of the international kilogram made it possible to verify masses from 0.1 milligram to 20 kilograms. For their comparison, a number of precision balances were under construction to give the Bureau a complete series of the very best balances possessed anywhere.

For determining the density of solids and liquids, the section had secured two sets of Jena glass hydrometers and verified them at the Normal Eichungskommission in Berlin. The section was working on means for standardizing capacity measures from 1 milliliter to 40 liters and also on

[50] "* * * where ordinary reading of micrometers to thousandths of an inch is pretty generally understood, reading to 10-thousandths is not." Joseph V. Woodworth, American Tool Making and Interchangeable Manufacturing (New York: Norman W. Henley. 1911), p. 270.

methods for testing a variety of chemical measuring apparatus in large quantities, for which there had been insistent demands. Apparatus designed at the Reichsanstalt for testing aneroid barometers had been secured, and in the planning stage was a new program, the testing of watches and other time-measuring apparatus.

As primary standards, the *heat and thermometry* section had acquired a number of specially constructed mercury thermometers in Paris, verified at the International Bureau of Weights and Measures in the range −30 to 550 °C. Gas-filled thermometers and copper-constantan thermocouples, also verified at Sèvres, were available for low temperature work down to −200 °C. In addition, Dr. Waidner had himself constructed as further primary standards several platinum resistance thermometers in the interval between 100 and 600 °C, as well as the necessary apparatus for their comparison. As working standards in this same interval were special mercury thermometers of both French and German make, and these were intercompared from time to time with the platinum resistance thermometers.

The Bureau was therefore prepared to certify almost any precision thermometer used in scientific work, most low-temperature engineering and industrial thermometers, and all ordinary commercial thermometers. In addition, special apparatus had recently been designed and constructed for testing clinical thermometers on a large scale, permitting 600 of them to be read at any given temperature in half an hour.

For high-temperature measurements between 600 and 1,600 °C, the Bureau had as primary standards a number of thermocouples acquired in Berlin, their scale that used at the Reichsanstalt. (Here it might be mentioned that America's dependence upon German science and technology before World War I was never more clearly demonstrated than in the circumstances of the Bureau's acquisition of its initial basic instrumentation.) With its German instruments, the Bureau was ready to test and calibrate extreme range thermocouples, platinum resistance thermometers, and expansion and optical pyrometers; determine the melting points of metals and alloys, as well as their specific heats and coefficients of expansion at high temperatures; and to determine the calorific value of any fuel in common use.

Establishment of these standard scales and the development of the necessary testing apparatus had taken most of the effort of this section since 1901. Now with much of the basic work completed, Waidner and Burgess were beginning exploratory research in some of the problems raised by these scales.

Work in the *light and optical instruments* section had thus far been chiefly confined to preliminary investigations in spectroscopic methods of analysis and the determination of standard wavelengths and their use in optical methods of measurement. While waiting on facilities to be provided in the new physical laboratory, Nutting was in the midst of an investigation of electrical discharges in gases in connection with spectrum analysis, and Bates was at work on new methods and apparatus looking toward improved polariscopic standards. At the request of the Treasury, Noyes and Bates had already begun supervision of the polariscopic analysis of sugar at the customhouses.

The *engineering instruments* section was currently occupied with planning tests of gas meters, water meters, pressure gages, and other instruments used in large numbers by public utilities for production control and for determining consumer rates. By far the largest piece of equipment destined for this section was a 100,000-pound machine for testing the strength of building materials. It seems possible this was acquired not long after the Bureau learned that the Reichsanstalt had under construction a new laboratory structure, the Material Prufungs Amt, for testing engineering and building materials.[51] The Bureau similarly planned studies in the behavior of structural and building materials when this crushing machine and other equipment on order were properly set up in North building.

In the *resistance and electromotive force* section of the electrical division, Dr. Wolff and his assistants had been kept busy making tests for Government agencies and for the electrical industry, verifying resistance standards for current measurements, testing standard cells, and determining the temperature coefficients and thermoelectric properties of resistance materials. Every calibration of an electrical instrument, all ratings of electric light bulbs, and practically every meter by which electricity was sold to home or factory started with a measurement of the device against a 1-ohm standard of resistance and a standard cell, by which the electrical pressure (electromotive force), and the current were determined. The Bureau had a number of 1-ohm manganin standards acquired at the Reichsanstalt and reverified there from time to time, using the primary mercury standards maintained in that laboratory. Wolff intended soon to construct a number of his own primary mercury standards in the Bureau shops.

No such effort at independence was necessary in the case of the Clark standard cell, the legal standard of electromotive force. At the electrical congress held during the Columbian Exposition in 1893, its value had been established as 1.434 international volts at 15 °C. Since then the Reichsanstalt, using the same cell as its standard, had determined a new value, 1.4328, nearly 0.1 percent smaller, and the Bureau hoped to settle this discrepancy at the next international electrical congress.

Work had just begun in the *magnetism and absolute measurement of current* section, where Guthe and Rosa were in the midst of two important

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[51] See Hearings * * * 1906 (December 2, 1904), p. 233.

researches. One was a study of the silver voltameter, used in measuring current; the other comprised two closely related studies, a redetermination of the electrochemical equivalent of silver and of the absolute value of the Clark standard cell and its rival, the Weston cell.[52]

Dr. Rosa's account of the *inductance and capacity* section suggests that he thought it probably one of the best and most completely equipped at the Bureau. As section chief, with Dorsey and Grover running the research, he had high hopes for the work it had begun. Hundreds of mica and paper condensers had been purchased from German, English, French, and American firms and studies made to find the best performance among them as standards of capacity. Two large air condensers had been constructed as loss-free working standards against which commercial condensers sent to the Bureau were compared. In conjunction with new apparatus under construction, these air condensers were to make possible absolute measurement of currents and electrical pressures up to 1,000 volts.

With a carefully constructed absolute standard of inductance (an electrical quantity analogous to mechanical inertia), the section planned, "by a method never before used," a new determination of the ohm, preliminary to an extended investigation in the absolute measurement of the fundamental electrical units, the ohm, volt, and ampere.[53] Establishment of the Bureau's standard of inductance would also make possible a thorough study of common sources of error in inductance measurements, of considerable concern to new developments in the communications industry.

The *electrical measuring instruments* section, also under Rosa's fervent eye, possessed a wonderful array of precision instruments for measuring electric current, voltage, and power, both direct and alternating, acquired from the best instrumentmakers at home and abroad or designed and built in the Bureau shops. The section was prepared to test and calibrate any laboratory or commercial instrument then in use. Its heavy equipment included powerful direct-current as well as alternating-current generators and allied equipment, and in testing direct-current instruments the section was prepared to handle capacities up to 1,000 amperes and 1,000 volts. The first high-voltage studies would begin with the installation of a giant storage battery with a potential of several thousand volts, then under construction for the Bureau.

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[52] The Clark cell, invented in England, had been in use since 1872. The American Weston cell, using cadmium instead of zinc, appeared in 1893, and at the turn of the century, because of the availability of better chemical components, was being made in Berlin. The superiority of the Weston cell had led to its adoption as a working standard by the PTR. In 1908, by international agreement, it displaced the Clark cell as the standard of electromotive force.

[53] Stratton and Rosa, "The National Bureau of Standards," Proc. AIEE, 24, 1075 (1905).

The work begun by Dr. Wolff in *photometry* had been turned over to Mr. Edward Hyde, who was studying a number of photometric standards acquired from the Reichsanstalt. Among his problems was the ratio of the candle to the Hefner amylacetate lamp which he had determined as 1 to 0.88. In preliminary tests the Hefner lamp, generally accepted abroad as a primary photometric standard, proved to have so many defects as to be unfit for measurements of the accuracy he hoped to attain. The Bureau had therefore established a temporary standard by arbitrarily assigning a mean value for a number of ordinary 16-candle commercial carbon filament lamps. By means of potentiometers, current and voltage to the lamps could be kept constant to within one-hundredth of 1 percent while making comparisons. Thus very accurate comparisons and very exact copies of standards were possible.

The Bureau had recently requested a number of lamp manufacturers in this country to submit carefully rated samples of their 16-candlepower lamps for comparison with the Bureau standards. They were found to vary from 15.4 to 17.6 candlepower, averaging 16.48 candlepower or about 3 percent high. This fairly close agreement resulted, the Bureau learned, from the manufacturers' use, as standards, of incandescent lamps rated at the Reichsanstalt.

But these were "model" lamps that had been sent to the Bureau. Subsequent testing of the commercial product was to reveal wide variations in their performance. Meanwhile, until the Bureau had devised methods for testing commercial lamps on a large scale, it could only verify those used as industrial standards or make special investigation of any particular lamps submitted to it. Better lamp and light standards and many other aspects of photometry remained to be explored, and this work would be pressed when the section moved into its new quarters.

The *chemistry* division, not yet organized, was to be headed by Dr. William A. Noyes, who had come to the Bureau from Rose Polytechnic Institute, where his starting salary had been the highest ever offered to a professor there. Through the courtesy of Professor Remsen, he was now at the Johns Hopkins University making a study of chemical standards needed in research laboratories, his quest interrupted by occasional trips away to supervise sugar analyses at the customhouses. His associate, Dr. Stokes, appointed from the Geological Survey, was at Dr. Wiley's Bureau of Chemistry in the Department of Agriculture, investigating equipment and measurement problems of its chemists with which the National Bureau of Standards might assist. As soon as Noyes and Stokes moved into their new laboratories and acquired assistants, they would begin much needed work on the standardization of some of the more important chemical reagents. They would be busy, too, assisting the other sections of the Bureau in the chemical analysis of materials going into the construction of standards.[54]

In addition to all the work on standards, instrumentation, and planning of research in that period, the number of tests made for universities, industry, and Government agencies had increased eight times over that possible in the former Office and would more than double again within the year. Surveying this program, Dr. Stratton had cause to be proud of the bureau he had constructed. In a little more than 3 years he had put together the men and materials for an organization that, "judged by the magnitude and importance of the output of testing and investigation," said Rosa, "ranked second only to the great German Reichsanstalt among the government laboratories of the world doing this kind of work." [55]

A sound beginning had been made in the formulation of standards and the main lines of their further investigation were laid out. The Bureau was humming. Fresh from a tour of the highly complex laboratories nearing completion on Connecticut Avenue, Stratton reported to a subcommittee of Congress: "You will not find the same combination of apparatus nor as complicated machinery except in . . . a battleship." [56] It was a neat thrust, considering that the entire cost of the Bureau to date came to less than a sixth of the price of just one of the great fleet of battleships President Roosevelt was currently building.

AN AUTUMN FIRE AND A CONSUMERS' CRUSADE

As the Bureau announced itself ready to expand its testing program in the late spring of 1904, the electrical division, with the help or advice of practically everyone else at the Bureau, was building a special electrical testing laboratory to take out to the Louisiana Purchase Exposition. The fair, celebrating the hundredth anniversary of the purchase of the territory, and the first of countless occasions for exhibiting Bureau activities, opened in St. Louis that summer.[57]

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[54] For additional notes on the early chemistry division, see letter, Campbell E. Waters to John F. Waldron, Jr., Aug. 15, 1940 (NBS Box 442, IC).

[55] Rosa, "The National Bureau of Standards and its relation to scientific and technical laboratories," Science, 21, 162 (1905). Based on an address given at Wesleyan University, Dec. 7, 1904.

[56] Hearings * * * 1906 (Dec. 2, 1904), p. 230.

[57] Details of this and other NBS exhibitions from 1904 to 1922 will be found in NBS Box 21, PE.

Once there, several members from Dr. Stratton's division presided over an historical exhibit of weights, measures, and instruments located in the Government building, while 10 from Rosa's division, at the request of the Exposition authorities, were kept busy in the great Palace of Electricity verifying the measuring instruments used by the jury of awards in testing electrical machinery, instruments, and apparatus submitted by exhibitors in competition. The German exhibits, as might be expected, won hands down. But for its design as a working exhibit and for its service to the many electrical interests at the fair, the Exposition authorities awarded the Bureau's laboratory one of the grand prizes.[58]

When free from Exposition commitments, the electrical staff carried out considerable routine testing and even some research in its Palace laboratory. More a novelty resulting from Nutting's gas spectra work than a piece of serious research, however, were the luminous script signs in glass tubing exhibited by the staff at the fair. When excited by electric discharges, the noble (inert) gas in the tubes—it was neon—lit up with a reddish glow.[59] Its commercial application came 26 years later.

The Bureau's self-contained electrical exhibit, cooled all that hot humid summer by a 10-ton refrigerating machine, "was a favorite retreat for the electrical jury," and its wizard equipment remained a special attraction until the end of October. Elsewhere on the fair grounds was another kind of "cooler," the first liquid hydrogen plant seen in this country, designed by James Dewar of the Royal Institution in London and exhibited at the fair by the British Oxygen Co. As an instrument of research, particularly in low-temperature thermometry, it was a prize, and Rosa at once began negotiations to acquire it. In Washington, Dr. Stratton approached Congress and obtained not only the asking price for the plant, £500 ($2,400), but an additional $12,000 for the construction of a low-temperature laboratory to house

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[58] MS, Dorsey, "Some memories of the early days"; Stratton and Rosa, Proc. AIEE, 24, 1084–1090 (1905).

[59] Dr. Nutting's neon signs—two special glass tubes blown by Mr. Sperling in the Bureau shops, one reading "HELIUM," the other "NBS"—resulted from a modification he made in the laboratory instrument known as the Plücker tube and reported in NBS Scientific Paper No. 6, "Some new rectifying effects in conducting gases" (1904). The Plücker tube, like the earlier Geissler tube, was used in the study of spectra of gases and metals. By substituting rod or disk aluminum electrodes for the thin platinum wire in the tube, Nutting obtained a much steadier and brighter light. Although never made public, the neon phenomenon has long been considered the Bureau's first notable laboratory accomplishment, and the forerunner of modern neon signs and fluorescent lamps. Interview with Dr. William F. Meggers, Aug. 4, 1964.

A series of charts of significant scientific and technologic achievements of the Bureau, for each of the decades covered by the chapters of this history, will be found in app. K.

it, adjacent and connected by tunnel to the North building.[60] The first cryogenic (low-temperature) investigations at the Bureau were begun by Franklin Durston that same year. The new building was not completed until the spring of 1906.

Although the Bureau up to this time had been principally concerned with establishing fundamental standards and planning basic research programs, an incident late in the autumn of 1904 sharply reminded the staff of its responsibilities in the field of commercial standards. One evening a fire started in the dead leaves near the railed boardwalk that had been built from the top of the hill down through the woods to the avenue. Franklin Durston, who as a very junior member of the electrical division was also acting night watchman, got out all the hose in the North and South buildings to get a line to reach the fire. He found that because of differences in the threads the hoses could not be coupled. With some difficulty and damage to his shoes, the fire was finally stamped out. The next day "there was quite a discussion as to how it happened that hose from two buildings of the National Bureau of Standards was not sufficiently standardized to admit of mutual coupling." [61]

The same lack of uniform threads had been largely responsible for the raging destruction of the great Baltimore fire back in February of that year. Engine companies arriving by special train from Washington within 3 hours after the fire began found themselves helpless when their hoses would not fit Baltimore hydrants. As one by one "completely fire-proofed" buildings burned like torches all that day and the next, and the fire raced through block after block of the business district, additional fire units from the nearby counties, from New York, Philadelphia, Annapolis, Wilmington, Chester, York, Altoona, and Harrisburg, arrived in the city only to discover that few of their hoses matched any other or fitted the local hydrants.

"If there had been nozzles enough, we could have flooded the burning district," the Baltimore Fire Chief said afterward, for at no time was there any shortage of water. Instead, 1,526 buildings and all electric light, telegraph, telephone, and power facilities in an area of more than 70 city blocks

[60] Stratton and Rosa, Proc. AIEE, 24, 1056 (1905). Stratton foresaw need of still another building, attached by tunnel to the opposite or east end of North building, to house laboratories for the testing of engineering instruments and structural materials, and two additional buildings, each about the size of South building, at the east and west ends of that structure, one exclusively for electrical work, the other for chemical and metallurgical studies (ibid., pp. 1041–1042). These four new structures, as detached wings of North and South buildings, were to be enclosed by the east and west buildings proposed earlier. Why the Bureau plant did not expand in this fashion has not been learned.

[61] MS, Dorsey, "Some memories of the early days."

The Baltimore fire of 1904. The turn of the century was still an age of kerosene lamps and wooden cities, except in the business districts which were largely of "fire-proof" brick and stone. But there were wooden stables and sheds behind the buildings, and the structures themselves were filled with highly combustible partitions and furnishings, and there was actually little that was fireproof in their construction.

Despite progress, as late as 1964 firefighters in at least one county adjacent to Baltimore were confronted with two types of hydrants in use, one with the national standard thread and the other with the Baltimore steamer thread. Although they had adaptors, the firemen were asking that fireplugs be coated with colored fluorescent paint, to distinguish the two threads at night and reduce delay in hooking up. The Baltimore Evening Sun, Oct. 1, 1964, p. D2.

in the business district were razed before the fire burned out, 30 hours after it began.[62]

For over a quarter of a century the National Board of Fire Underwriters and the National Fire Protection Association had been advocating standard couplings for all fire departments but had received little support. Shortly after the disaster, a Baltimore steamship line called on the Secretary of Commerce for help with shipboard hose and couplings and the Bureau of Standards was asked to investigate. Thus several months before its own humiliating experience, Stratton had already set Albert Merrill of the engineering instruments section to work on the problem of fire-hose couplings.[63] Before the investigation ended, over 600 sizes and variations in fire-hose couplings were collected across the country.

In 1905, a year after Merrill began his study, the National Fire Protection Association, with the active concurrence of the Bureau, adopted as the national standard what it considered the most serviceable hose coupling then in use, together with an interchangeable device for nonstandard couplings. But the expense of converting or replacing fire hose, as well as normal civic inertia, made agreement in the cities of the Nation a slow process. By 1914, 9 years later, the American Society of Mechanical Engineers reported that only 287 of 8,000 cities and towns had fire-hose couplings and hydrant outlets conforming to the standard. Up to 1917, 897 cities had agreed to adopt them, but only 390 had put them in service. By 1924 the number of cities with standard fire-hose couplings had risen to 700. Conversion was to continue at this slow pace. In many cases, municipalities would make the change only when they had experienced their own version of the Baltimore fire.[64]

Efforts at standardization in another direction offered somewhat better, and certainly more spectacular, results. They began in the spring of 1901 when Louis A. Fischer visited some of the larger cities in New York State to inquire about their inspection of commercial weights and measures. The answers were discouraging. On his return he made a compilation of the laws of all the States relating to weights and measures, revealing a hopeless tangle of regulations, as remarkable for their variety as for their inadequacy. Fischer's section subsequently drew up designs for simple, accurate,

[62] Harold A. Williams, Baltimore Afire (Baltimore: Schneidereith, 1954), pp. 11, 20, 43.

[63] Stratton and Rosa, Proc. AIEE, 24, 1070 (1905).

[64] NBS C50, "National standard hose couplings and fittings for public fire service" (1914, 2d ed., 1917). Press release, American Engineering Standards Committee (AESC), June 25, 1924, "Screw threads for fire hose couplings approved as American standard" (NBS Box 77, IDA).

NOTE.—C designates Circular of the NBS, as M, when cited hereafter will designate an NBS Miscellaneous Publication.

inexpensive working standards for the use of State, county, and city sealers and put them in the hands of several manufacturers. Thus sealers for the first time could buy sets of standard weights, measures, and scales specifically designed for their use and send them to the Bureau to be verified and certified.[65] But it was not enough. The old standards had been around a long time and there was no rush to acquire the new sets. The States had to be stirred up.

Dr. Stratton's first proposal to the Governors of the States in 1903 for a meeting of State sealers fell through, it was said, for lack of State travel funds. In November 1904, shortly after moving out of downtown Washington and into the new buildings on Connecticut Avenue, Stratton renewed the invitation. Although there were few acceptances, he was determined to hold the meeting anyway.

The first conference, meeting in January 1905, with representatives from seven States and the District of Columbia, disclosed that in most of these States the laws relating to weights and measures were "exceedingly lax * * * with nothing obligatory" or were "practically a dead letter," that the State sealer's office was usually unsalaried, and the duties of county sealers were often imposed on the county treasurer or even the superintendent of schools. In more than one State, the county and city sealers were not compelled to procure standards, and several of the State representatives knew nothing about their State standards or even where they were to be found. In one State Hassler's standards had been destroyed by fire some years earlier and the $550 necessary to replace them had never been appropriated. In another instance the standards were said to be "hoary with age from long confinement in the dingy and dark recesses of the basement of the capitol."

The consequence of this almost studied disinterest, it was admitted, had long made fraud and trickery in weights and measures commonplace in most of the States represented at the conference. And as Dr. Stratton commented: "Remarkable as have been the statements made today we have not heard the worst, as there are States in which absolutely nothing is done and which are not represented here today." The Bureau agreed to host further meetings in order to discuss means for securing uniform laws and inspection of commercial weights and measures.[66]

At the second conference, in April 1906, it was decided to set up a permanent organization of State officials, make the conference an annual event to discuss the testing and sealing of commercial weights and measures,

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[65] Letter report, Fischer to O. H. Tittmann, Supt., U.S. C. & G.S., June 15, 1901 (Stratton Papers, Box 12); NBS Annual Report 1904, pp. 6–7.

[66] "Conference on the weights and measures of the United States * * * January 16 and 17, 1905," NBS M4 (1905), pp. 26, 27, 31, 40, 42. See the voluminous correspondence with State officials in NBS Box 18, IW, 1901–11.

and work toward adoption of uniform laws. Seventeen States were represented at the third conference in 1907, and as at the previous meetings the discussion soon centered around "the question of honest weights and measures in all business transactions," the almost infinite variety of laws affecting weight and measures, and the meager funds provided by the States for their inspection. The conference began work on a model weights and measures law, to be offered for adoption by all the States, and recommended unanimously that additional powers be given the Bureau of Standards to make the State laws effective.[67] Such enforcement, of course, the Bureau could not undertake, but it offered its cooperation to State governments in establishing effective inspection systems while it sought other means to "police" weights and measures. The means was exposure.

Since 1901, as Stratton said, "a great reform [had been] going on throughout the country," its principal target the commercial oligarchy that ruled the Nation.[68] It had been touched off by journalists such as Ida M. Tarbell, Lincoln Steffens, and Ray Stannard Baker through their exposure in the periodical press of the knavery in big business, the roguery of politics and politicians, of labor leaders and employers alike. Aroused by the literature of exposure, a passion for change, for honesty, and for justice swept the Nation. Among the consequences of the reform wave were Roosevelt's indictment of the meat-packing trust in 1905 and passage of the Pure Food and Drug Act in 1906.

Before the wave receded, the whole Nation became aware of the presence of the Bureau of Standards in the Federal Government. Beyond anything its proponents could have contemplated, the coincidence of the founding of the Bureau with the age of reform shaped its history for the next 30 years. Weights and measures was to be the trigger.

The annual conferences of State sealers at the Bureau made it clear that through ignorance and neglect of State responsibilities the American public was being robbed of enormous sums daily in the marketplace. Since the State governments showed little interest in weights and measures reforms, said Stratton, the Bureau "must reach the public through State and city officials by testing their standards." In December 1908 he asked Congress for a special grant of $10,000 "to investigate what the States are doing with their standards, and to encourage them to take up and supervise the local work as they should."[69] It was the Bureau's first request for special funds, and Congress approved it without question. What Stratton intended was an investigation to reveal the extent of false and fraudulent weights and measures in use throughout the Nation.

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[67] NBS Annual Report 1907, p. 6.

[68] Hearings * * * 1908 (Nov. 30, 1906), p. 351.

[69] Hearings * * * 1910 (Dec. 4, 1908), pp. 185–186.

Between 1909 and 1911, inspectors from the Bureau visited every State of the Union, testing over 30,000 scales, weights, and dry and liquid measures in 3,220 different shops and stores. They were not surprised to find that almost half the scales tested were badly inaccurate, that 20 percent of the weights, half the dry measures, and a quarter of the liquid measures were in error; or that with remarkable consistency these scales and measures favored the storekeeper. The Bureau estimated that in the case of print butter alone the annual loss to the consumer, through rigged or faulty weighing devices, amounted to more than $8,250,000.[70]

From the start, journalists and reporters followed the track of the Bureau inspectors, and with the first disclosures of what the journalists termed "the knavish distortion of weights and measures," the crusade began. New York State's superintendent of weights and measures, Dr. Fritz Reichmann, and Mayor Gaynor of New York City soon launched investigations of their own and other States followed. Over the next 2 years almost a hundred articles in the periodical press reported the weights and measures campaign across the country.[71]

As a result of the widespread demand for better laws and better inspection of trade weights and measures in the wake of the survey, first New Jersey and then other States enacted the model law proposed by the Bureau, and State after State exhumed and submitted for verification to the Bureau the standards that had been furnished them some 50 years earlier or purchased new equipment for their State sealers.[72] Answering urgent appeals, the Bureau drafted a model weights and measures ordinance for municipalities, and detailed its experts to first one and then another of the States which requested aid in setting up their inspection departments.

A Bureau proposal to require that the net weight, measure, or numerical count of contents be printed on sealed packages was accomplished by an amendment to the Pure Food and Drug Act in 1913, and in 1915 Congress passed a standard barrel law; but efforts of the Bureau to promote national legislation to define the weights and measures used in everyday trade, to

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[70] Louis A. Fischer, "Recent developments in weights and measures in the United States," Pop. Sci. Mo. 84, 345 (1914), reported the Bureau's findings, State by State. See also NBS Box 18.

[71] For example, F. T. Cordage, "Serious leakage: short weights and measures," Good Housekeeping, 48, 744 (1909); F. Reichmann, "The necessity of the supervision of weights and measures," Am. Stat. Assoc. 12, 146 (1910); Sloan Gordon, "Is the housewife guilty?" Cosmopolitan, 50, 73 (1910); Francis J. Dyer, "The Government to the rescue," Good Housekeeping, 52, 334 (1911). In Reichmann's "Savings through proper supervision of weights, measures and standards," Ann. Am. Acad. Pol. Soc. Sci. 50, 94 (1913), he estimated that as a result of reforms in New York State, annual savings to consumers in the past several years had amounted to $15 million.

[72] NBS Annual Report 1909, pp. 11–12.

fix the sizes of other common shipping units besides the barrel (such as the bale, box, and basket), and to require certification by the Bureau of all weights and measures apparatus manufactured and sold in the United States, got nowhere.[73]

The crusade ended, but not before the Bureau had made the Nation conscious of the meaning of measure at the market—temporarily, at least. Ninety-eight officials representing 25 States and 34 cities attended the Bureau conference held in February 1912, and except during wartime years, these conferences have been held annually ever since.[74] Through the conferences, the continuing research at the Bureau, the training of sealers, and the furnishing of informaton and assistance to State and local officials, the pioneer work of Louis A. Fischer lives in the weights and measures control we know today.

THE BEGINNING OF GOVERNMENT TESTING

The era of exposure not only served to acquaint the general public with the name of the Bureau of Standards but it brought to the notice of other agencies of the Government a new and versatile auxiliary in the Federal family. Even before the weights and measures crusade began, the Federal Government, alerted by the hue and cry of the reformers calling citizens and consumers to arms, discovered that as a consumer it was itself being victimized.

Incandescent lamps, bought by the Government at the rate of a million a year, were burning out at a fearful rate in Federal offices. When a purchasing agency sent one of its recent shipments to the Bureau for tests, the Bureau promptly threw out three-quarters of the bulbs. They were neither uniform in accordance with the manufacturer's own standards, nor did they even come up to the simple specifications suggested by the Government. The Bureau was soon to find similar shortcomings in the clinical thermometers, electric meters, chemical glassware, inks, mucilages, and indeed the whole catalog of supplies purchased for Government use.[75]

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[73] NBS Annual Report 1911, pp. 13-15. NBS C61, "Specifications and tolerances for weights and measures and weighing and measuring devices" (1916, 2d ed., 1920), was adopted at the weights and measures conference of 1916 for use in ordinary commercial transactions and had wide acceptance.

[74] By 1929 the Bureau reported there were almost 300 officials on the State level dealing with weights and measures work and 1,400 on the local level (NBS letter report, May 2, 1929, NBS Box 285, IW). For later reports, see NBS M172, "Index to reports of the National Conference on Weights and Measures, 1905-41" (McCormac and Smith, 1942).

[75] Hearings * * * 1906 (Dec. 2, 1904), pp. 231-232; Hearings * * * 1909 (Jan. 30, 1908), pp. 496-497.

The light bulb incident occurred in 1904. By 1906, Stratton reported, there was "a wave of reform going on all through the Government service as to proper specifications and proper tests to determine whether goods purchased complied with specification." [76] And Bureau testing for the Government began to double annually as increasing varieties and quantities of Government supplies and materials were sent to the Bureau before acceptance. The Bureau was called on to test the tensile strength of a new cable for the elevator in the Washington Monument, the cement used in the construction of the new House Office Building, paper and inks for the Government Printing Office, paints, oils, and varnishes for the Lighthouse Board, and virtually every instrument and piece of apparatus destined for a Federal laboratory.

Congress, concerned over the repeated increases in personnel and funds that Dr. Stratton found it necessary to ask for, complained that it was "shocked a little bit by the way [the Bureau] is developing." In answer to the question, "Do you not think that you are broadening the scope of the work of your Bureau?" Stratton described the growth of the Government testing program.[77] This testing had not been specified in the organic act, nor even contemplated when the Bureau was founded. But the Bureau laboratories were uniquely well fitted to make such tests, and great economies accrued to the Government as a result. It was, Stratton told Congress, almost entirely "commercial testing" and offered little opportunity for original investigation or research; still, it necessitated hiring specialists in many fields and large numbers of aids, apprentices, and assistants.

By 1908 two-thirds of all testing at the Bureau was for Federal agencies alone. During that year it carried out tests for 37 bureaus and divisions of the Government, analyzing rag and wood papers for the Post Office Department and the Government Printing Office, investigating naphthas and celluloids as cargo hazards for the Steamship Inspection Service, assisting in Pure Food and Drug Law analyses, and carrying out a long series of cement and concrete examinations for the Panama Canal Commission. As an illustration of the usefulness of its tests, said Stratton, the Bureau had recently rejected outright 4 of 6 samples of varnish and 14 of 24 samples of paint submitted for analysis by the Lighthouse Board.[78]

So extensive had this testing program become by 1909 that the Bureau had to restrict its own research and was experiencing difficulty in handling

[76] Hearings * * * 1908 (Nov. 30, 1906), p. 351.
[77] Hearings * * * 1904 (Dec. 2, 1904), p. 229; Hearings * * * 1907 (Feb. 23, 1906,) p. 657.
[78] Hearings * * * 1909 (January 30, 1908), pp. 495–496; Hearings * * * 1910 (Dec. 4, 1908), p. 171.

requests for investigations from university and industrial laboratories. Stratton feared for the Bureau: "Nothing could cause the institution to deteriorate more quickly than to flood it with routine testing. It must do a certain amount of original investigation to develop standards and methods of measuring or it will soon become a second-rate institution." [79]

Yet in addition to greater economy in Federal housekeeping, much good was coming from the Government testing, as Stratton was well aware. It was supplying a much needed incentive to industry. The high rate of rejection by the Bureau and the impartiality and justice of the tests thoroughly alarmed hundreds of firms supplying goods and materials to the Government. Supplying the Government was good business, and even though the Bureau did not publish its findings by brand name, word got around. A manufacturer or supplier who lost a Government contract found he lost other contracts. Manufacturers began beating a path to the laboratories on the hill for advice and help with their materials, measuring, and testing apparatus, and methods of quality control.[80]

"Scarcely a day passes," Dr. Stratton reported, "that some manufacturer does not visit the Bureau to learn how to measure or to secure standards." In many instances the Bureau did not have the answers industry sought, since no criteria existed for the products or materials in question. But with the manufacturer's assistance, the Bureau would agree to undertake the necessary research and establish the required standard. In this manner industry, and Government agencies as well, were to provide the kind of research the Bureau wanted to do.

The Bureau was quick to see the importance to the public as well as to industry of expanding its random commercial testing for the Government into a large-scale research program that would cover as widely as possible the range of materials and products of commerce. As early as 1905 the Bureau reported that "numerous cases of dispute regarding the quality of construction materials, such as iron, steel, brick, stone, cement, concrete, etc., have been referred to the Bureau for a determination of the physical properties in question." [81] Virtually no data existed, for example, on the tensile and compressive strength, specific gravity, and time of set of cement and cement mortars, or on the thermal conductivity and effects of temperature upon the compression, expansion, and durability of concrete aggre-

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[79] Hearings * * * 1910 (Dec. 4, 1908), p. 177.

[80] As Henry S. Carhart pointed out in Pop. Sci. Mo. 79, 209 (1911), the Government purchased only about 1 percent of the incandescent lamps made, the other 99 percent being sold to the general public, but Bureau testing elevated the quality for all.

[81] NBS Annual Report 1906, p. 15.

gates, poured concrete, or concrete building blocks. And so with other construction materials.

Search of the literature on materials submitted for Government purchase disclosed that no standard methods or apparatus existed for the testing of wood, paper, twine, textile fabrics, inks, mucilages, and related materials, or for the testing of lubricating oils, resins, varnishes, protective coatings, and glues, all of whose qualities were as important to the buying public as to the Government. In order to provide proper specifications to industry for the manufacture of these materials, the physical, chemical, and other properties of their composition had to be investigated. The program of structural, engineering, and miscellaneous materials research thus begun was to consume much of the Bureau's energies for many years to come. By 1911 the program, originally scattered throughout the laboratories, had attained divisional status. It had a special appropriation of its own, and was well on the way to becoming the largest single activity at the Bureau.

Allied to this research in commercial and industrial products, but actually derived from the function calling for "the determination of physical constants and the properties of materials," was the Bureau's standard samples program. This began in 1905 when the American Foundrymen's Association turned over to the Bureau its work of preparing and distributing samples of standardized irons to its member industries. To prepare these samples, a quantity of iron was reduced to fine borings and then carefully analyzed, divided into samples of known composition as certified by the Bureau, and sold to manufacturers as a check on their own laboratory analyses.

Preparation of like samples of a number of alloys, iron ores, and copper slags prompted Albert Ladd Colby, representing engineering interests on the Visiting Committee to the Bureau and a leading authority on metallurgy, to suggest that the Bureau produce samples of steels as well. The work began the next year when the Association of American Steel Manufacturers requested preparation of a series of 17 standard steel samples. The Bureau's samples won high praise and requests for similar certification of other basic materials. When the American Chemical Society assigned its standard sample work to the Bureau, Dr. Stratton announced the Bureau's intention of preparing an entire spectrum of sample materials, covering hundreds of products, for American industry.[82]

The chemistry division, increasingly involved in its investigation of properties of materials for the Government testing program, found itself

[82] NBS Annual Report 1906, p. 16; Annual Report 1907, p. 13. The methods of analyses and range of samples were described in NBS C14 (1909), NBS C25 (1910), NBS C26 (1910) and their successive editions.

pressed for time and staff as the work on standard samples grew. Nevertheless it borrowed time from these efforts to launch a much needed investigation of impurities in analytical chemicals. Other groups at the Bureau, now grown to divisions, were also pushing out exploratory parties into new lines of inquiries. The weights and measures staff had begun its investigation of State standards, the pyrometry and heat divison sought new methods and instruments for high-temperature measurement in industry, the optics division attacked theoretical problems in polarimetry, spectroscopy, and radiometry, and the electrical division became involved in absolute measurement, electrical instrumentation, and photometry. But making constant inroads into the research efforts of all divisions was the acceleration of routine testing and calibration for science, industry, and above all for the Government. Between 1905 and 1910 the number of such tests increased from 16,500 to almost 50,000, the Government's share rising from 26 to 70 percent of all calibration and testing. And complicating the testing was the demand for new research in technology, in order to establish a methodology and instrumentation that would put testing on an increasingly scientific basis.

The volume of testing, doubling in 1909 over the previous year under the impact of Government work, soared again the next year when, to consolidate effort and responsibility, the staff and equipment of the structural materials laboratories of the Geological Survey were transferred to the Bureau of Standards.[83] The transfer on July 1, 1910, involved 53 engineers, chemists, and assistants. It included a small group in Washington under Dr. Samuel S. Voorhees, who with his chief assistant Phaon H. Bates was engaged in chemical research in mineral pigments, paints, and other building materials, mainly for the Supervising Architect's Office; a Pittsburgh laboratory under Dr. Albert V. Bleininger, where cements for navy yard and dry dock construction, as well as clays, ceramics, lime, steel, and other structural materials were tested; a Northampton, Pa., laboratory under R. L. Humphrey, testing cement at the plants supplying the Isthmian Canal Commission; and still another laboratory at Atlantic City under Rudolph J. Wig, where the effect of sea water upon concretes and protective coatings was being investi-

[83] The Geological Survey, ordinarily concerned with assaying and mapping the earth resources of the Nation, began its structural materials program in 1904 when it was persuaded to make tests of cement-making materials, building stones, and clays for an exhibit of the American Portland Cement Manufacturers at the St. Louis fair. By 1910 the Survey, since restricted by law to research for the Government, was testing a wide range of structural materials, principally for the Panama Canal (under construction from 1904 to 1914) and for some 400 public buildings planned or under construction in the United States. See Annual Report, Department of the Interior, 1910, pp. 202, 206; Weber, The Bureau of Standards, pp. 48–49.

The Bureau about 1910, just prior to the construction of the electrical laboratories (East building). From left to right: the corner of West building, South building, the Low Temperature Laboratory, and North building.

gated. Soon after, the Bureau itself established a fifth field laboratory, at Allentown, Pa., to sample and test cement produced in plants there for the Navy and War Departments.[84]

Well before this augmentation of the Bureau, its test program had already crowded into the last of the laboratories available in North and South buildings. Planning expansion of both the Bureau's work in structural materials and that of the former Geological Survey group, Dr. Stratton asked Congress for new mammoth testing machines and a special building to house them. The funds were approved and a 1-million-pound crushing machine for compression tests of brick, stone, cement, and concretes, another of 230,000-pound capacity, a 100,000-pound universal (compression and tension) machine, and a specially designed 2,300,000-pound Emery universal testing machine, for breakdown and exhaustion tests of girders and other large structural members, all built to Bureau specifications, were ordered.[85] Well before they arrived, West building, a four-story laboratory situated between North and South buildings, was completed in December 1909 at a cost of $175,000.

Surpassing West building's giant Emery machine in capacity if not design was the Olsen machine acquired with the Pittsburgh laboratory. It was the most powerful testing machine in the country at that time, capable of exerting a force of 10 million pounds slowly and irresistibly in destruction tests of massive masonry columns. Structural materials testing at the Bureau and its field stations, nowhere contemplated in the organic act, began to expand.

In 1911, with almost no further increase in staff over the previous year, the number of tests and calibrations leaped from 50,000 to more than 80,000, almost 77 percent of them for the Government. The Bureau was to maintain this level until we entered the war in 1917.

Largely as a consequence of the Government testing program, authorized personnel for the Bureau, including the group transferred from the Geological Survey, rose from 87 to 269 between 1906 and 1911. Acquiring that number of trained scientists and craftsmen—and keeping them—had for some time become a serious problem. The Bureau could not compete in salaries either with the larger universities or with industry, and the increasing interest of manufacturers in the application of science to industry made them particularly eager to entice specialists away from the Bureau. Industry was willing to pay twice the Government salary for men it wanted and even

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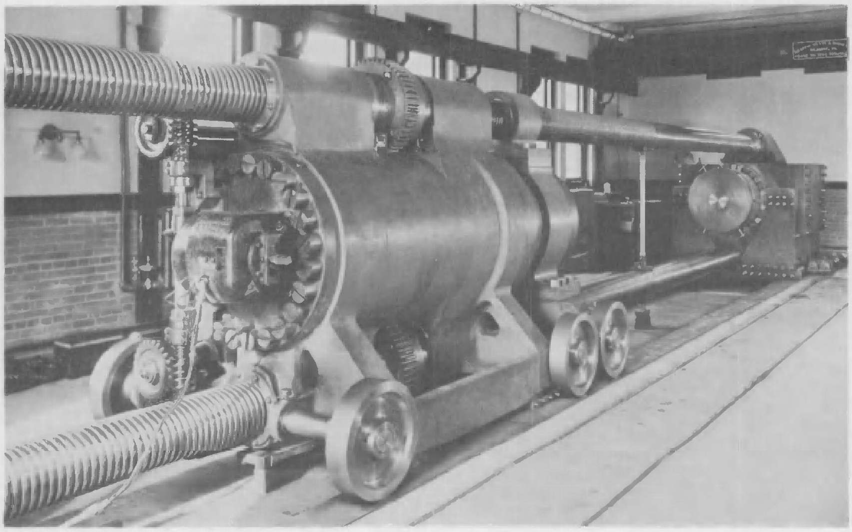
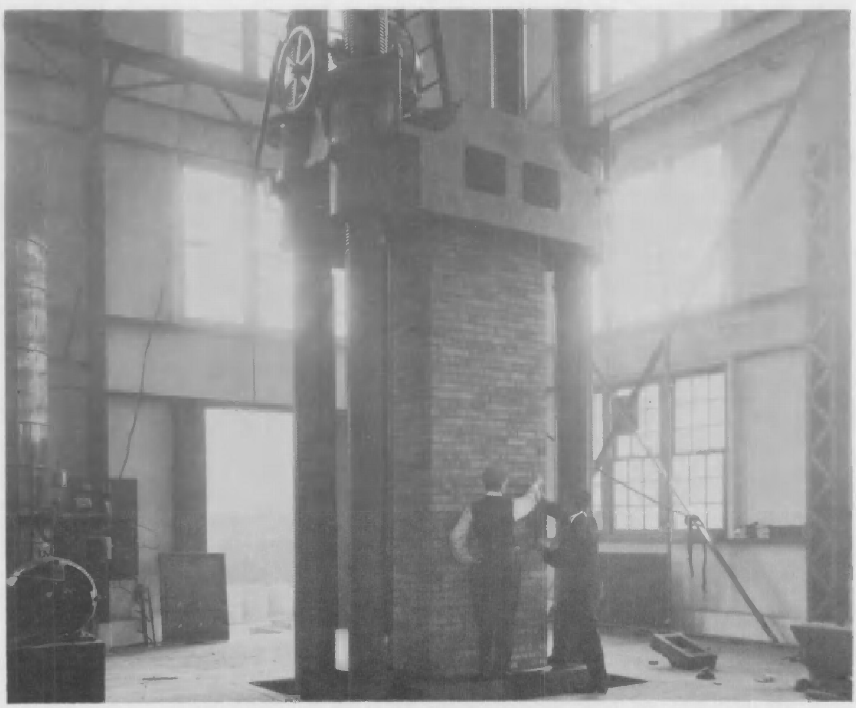
[84] Annual Report, Department of the Interior, 1910 p. 297; ibid. 1911, p. 377; NBS Annual Report 1911, pp. 26-28.

[85] Detailed descriptions and correspondence concerning the acquisition of these machines will be found in NBS Box 5, EI.





The 2,300,000-pound Emery testing machine in Washington, for making exhaustion tests of beams, girders, and other large metal structural components. A similar compression-to-exhaustion giant, the Olsen machine, was at the Pittsburgh laboratories, for destruction tests of piers and other masonry columns.

the universities offered lures hard to resist, as Dr. Stratton demonstrated graphically at a congressional hearing in 1906: [86]

Harvard University		*Bureau of Standards*	
Instructor	$1,200-$1,500	Laboratory assistant	$ 900-$1,200
Assistant professor	2,500- 3,000	Assistant physicist	1,400- 1,800
Associate professor	3,500- 4,500	Associate physicist	2,000- 2,200
Professor	4,000- 5,500	Physicist	3,500- 4,000

The Bureau, said Dr. Stratton, had lost a number of its staff that year, and some of its most valuable members were strongly tempted to leave. One was Dr. Noyes, the Bureau's chief chemist, who between 1904 and 1907 had won international fame for his development of standard methods of analysis and standard specifications for chemicals while at the Bureau. He had had university offers as high as $4,750, although the Bureau could not pay him more than $3,500. Two years later Dr. Noyes went to the University of Illinois as head of its chemistry department. Dr. Rosa refused an invitation to go to MIT, but Dr. Edward Hyde, in charge of Bureau research in photometry, left his $2,000 position for similar research in the Edison lamp laboratories at $5,000 a year.

Congress was not inclined to be sympathetic about such losses. "Is not that thing likely to occur with any reasonable salary that the Government can pay?" asked Washington Gardner, Republican representative from Michigan and member of the House Subcommittee on Appropriations. It was, Dr. Stratton replied, but the nature of the work at the Bureau made its staff particularly vulnerable to good offers outside, especially since "nearly every great manufactuing concern in this country is establishing a research laboratory" and looking for trained men. "I think it [is] a good thing for the country to have them go out into the world," answered Mr. Gardner, and suggested that the Bureau continue to hire men at its lower grades and promote them as vacancies occurred.[87]

Despite the low salaries, employment with the Bureau of Standards had many compensations, not least the prestige of working for a new, important, and rapidly growing scientific agency of the Federal Government. Status and tenure were apt to be more certain than in a university or in industry since all positions, then as now, were filled through competitive civil service examinations, thus guarding against personal whim or favoritism, with permanency and promotion determined by civil service law.

Except for division chiefs, whom he selected on the basis of demonstrated productivity and promise, Stratton, hampered by the competition in salaries, adopted the policy of bringing in talented graduates of first-class scientific or technical colleges, appointing them to the lower grades of

[86] Hearings * * * 1907 (Feb. 23, 1906), p. 602.

[87] Hearings * * * 1911 (Jan. 27, 1910), pp. 332-336.

assistantships, and advancing them as their proficiency increased and vacancies occurred. To provide minor assistants for routine testing and experimental work, he set up a system of apprentices and aids, taking on graduates of manual training and technical high schools as apprentices, advancing them to aids after 2 years, and thence to the lowest grades of laboratory assistant when they had acquired the requisite mathematics and training in theoretical science through evening courses given at George Washington University in downtown Washington.[88]

Many who were later to be luminaries of the scientific world came to the Bureau as laboratory assistants, among them Dr. William F. Meggers, dean of American spectroscopists; Dr. George K. Burgess, who succeeded Stratton as Director of the Bureau; Dr. Frederick J. Bates, one of the country's outstanding sugar physicists; Dr. William W. Coblentz, founder of modern radiometry; and Dr. Paul D. Foote, pioneer in high temperature measurements.[89]

The Bureau grounds, remote from the city, tree-shaded, and populated predominantly by young college graduates, possessed from the beginning an unmistakable campus atmosphere. The group loyalties and mild intramural competition that naturally resulted were diligently fostered by Dr. Stratton, as a means of keeping his staff from straying. He did more. Many of the young holders of B.S. and M.S. degrees who came to the Bureau, some with wives and all with ambition, wanted their doctoral degrees. Stratton proposed a plan for giving graduate courses at the Bureau in mathematics, physics, and chemistry equal to those in the best universities, and

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[88] Stratton and Rosa, Proc. AIEE, 24, 1043–1044 (1905).

[89] One measure of the caliber of the physicists that Stratton brought to the Bureau is represented in the star system of American Men of Science. From its first (1906) to it seventh (1944) editions, American Men of Science, by an intricate ballot system, periodically starred the thousand outstanding scientists in the Nation. Among the 150 top physicists (headed by A. A. Michelson) that were selected in 1906 (actually chosen in 1903), Bureau members included Austin, Dorsey, Guthe, Nutting, Rosa, Stratton, Waidner, and Wolff. (This 1906 list appeared in American Men of Science, fifth edition, 1933, pp. 1269 ff.)

By the fourth edition (1927), the Bureau had increased its number of leading scientists from 8 to 23 members, its group of physicists alone representing the strongest collection of any institution in the country, ranking above Harvard, General Electric, University of Chicago, Bell Telephone Laboratories, Johns Hopkins University, Columbia, California Institute of Technology, Cornell, and Yale. And at that time the number of entries in American Men of Science had risen from 4,000 (1906) to 13,500 (1927). Starred members of the Bureau in the 1927 edition included Acree, Austin, Bleininger, Blum, Briggs, Brown, Buckingham, Burgess, Coblentz, Crittenden, Curtis, Dellinger, Dickinson, Dorsey, Foote, Heyl, Meggers, Mohler, Skinner, Priest, Washburn, Wenner and Wolff (American Men of Science, fourth edition, 1927, p. 1128 ff. See also J. McKeen Cattell, "The scientific men of the world," Sci. Mo. 23, 468, 1926, and Science, 66, 516, 1927.)

permitting staff members to offer parts of their Bureau research results as graduate theses, provided their universities would accept this course work and research.

Precedent for the latter had been established even before formal adoption of the plan. Original research at the Bureau had been accepted toward the doctorate when the Johns Hopkins University admitted an investigation in photometry by Edward P. Hyde for his degree in 1906, when the University of Michigan accepted work on magnetic testing by Charles W. Burrows in 1907, and also that year when George Washington University accepted an investigation of capacity and power factors of condensers by Frederick W. Grover.[90]

The experience of Harvey L. Curtis, one of the first to secure his doctorate through Bureau courses and research, and long-time member of the electrical division, was typical of many who followed him. In the spring of 1907, with a master's degree in physics from the University of Michigan, a wife and two children, and 4 years' experience as instructor at $700 at Michigan Agricultural College, Curtis, then 31, chanced upon a notice of an examination for assistant physicist at the Bureau. He had just been promoted to assistant professor when he received word he had passed the examination. He was offered the Bureau appointment at $1,200. When he declined because the college assistant professorship paid better, Rosa sent him a telegram asking him to come to Washington anyway for an interview. He was offered $1,400, and was persuaded to accept when Dr. Stratton told him of the graduate course plan being inaugurated.

Soon after Curtis began work in the electrical laboratories, he wrote at Dr. Stratton's suggestion to Prof. Henry S. Carhart at the University of Michigan about the course plan. Carhart replied that the faculty had voted to give Curtis a hearing when he presented the completion of his work. Other youngsters at the Bureau, Roy Y. Ferner, Paul G. Agnew, E. C. McKelvy, J. Howard Dellinger, and Hobart C. Dickinson, also wrote to their universities. A few of the replies were discouraging, some were tentative, but Prof. Joseph S. Ames, head of the physics department at the Johns Hopkins, wrote enthusiastically to one of his former pupils:

> There is not a college or university in the United States that can give a student as much apparatus for experimental work and as

[90] H. L. Curtis, "Establishment of graduate study courses at the NBS," J. Wash. Acad. Sci. 29, 351 (1949). See also MS speech, G. K. Burgess, "The Bureau of Standards as an educational institution," June 28, 1924 (NBS Box 77, IDP). Memo, L. B. Tuckerman for L. J. Briggs, Oct. 12, 1927 (NBS Box 489, AP), reported that 11 of the 72 doctorates in physics granted by Johns Hopkins between 1906 and 1926 went to Bureau members, 2 others had received degrees for Bureau research in chemistry and 2 in electrical engineering. Dr. Briggs received his Hopkins degree in 1901 for work done at the Department of Agriculture.

much help in the theoretical field of the physical sciences as he can obtain at the Bureau of Standards.[91]

Stratton proposed a 3-year cycle of evening courses in physics, mathematics, and chemistry, each course to be given 2 hours a week for 30 weeks, at $25 per course. The first subjects offered in the fall of 1908 were in differential equations, given by Dr. John A. Anderson, who came out weekly from the Hopkins physics department; theoretical mechanics, taught by Dr. Albert F. Zahm of Catholic University; and thermodynamics, by Dr. Edgar Buckingham of the Bureau.

Dr. Rosa was to have given a weekly 4-hour course in experimental methods in electrical measurement that same autumn when a call for consultations on electrical standards at the British and German physical laboratories took him abroad. The course was given instead by three of the students who had signed up for it, Dellinger, then working in the resistance and electromotive force section, Curtis in the inductance and capacity section, and Agnew in the electrical instruments section. Upon his return in January 1909, Rosa completed the course with a series of lectures on advanced electrical measurements.

In the spring of 1909 a Bureau committee composed of Stratton, Rosa, Hillebrand, Wolff, Waidner, Burgess, Dorsey, Nutting, Waters, and Fischer was set up to direct the graduate program. To the classes already in progress, Dorsey began teaching a new course in electricity and magnetism and Dr. Kanolt began another in physical chemistry.

Including advanced work taken earlier at the University of Michigan, Harvey Curtis completed the course work at the Bureau in the spring of 1910. With his thesis on "Mica condensers as standards of capacity," based on a recently completed investigation published that same year in the Bulletin of the Bureau, he went to Ann Arbor, passed his orals, and returned with his degree.[92]

The cyclic system of graduate course work established by Dr. Stratton continued for the next 50 years, and what was begun as an expedient to keep promising personnel, came to attract them as well. In 1960, 1,322 members of Bureau laboratories and affiliates were taking a total of 72 undergraduate and graduate courses offered in the physical sciences, mathematics, and engi-

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[91] Quoted in H. L. Curtis, Recollections of a Scientist: An Autobiography (privately printed at Bonn, Germany: L. Leopold Press, 1958), p. 27.

[92] Ibid., pp. 22, 26–30. Three years later, in 1913, Dr. Curtis became an associate physicist at the Bureau, in 1918 physicist, in 1924 senior physicist, and in 1928 principal physicist. He published a book on electrical measurements and almost 50 papers prior to his retirement from the Bureau in January 1947. The retirement was purely statutory. Like many other long-time employees of the Bureau, Curtis continued to experiment as a guest worker in his old laboratory, coming in daily until shortly before his death at the age of 80.

neering for advanced degrees or promotion. Since Dr. Stratton established the graduate program in 1908, more than 15,500 registrations have been recorded, resulting in the award of 270 graduate degrees by 40 different universities, for research carried out in part at least at the Bureau.[93]

After the 1920's all the physical sciences were levied on for degrees, but in the age of electricity, as historians of modern technology have called the period prior to World War I, much of the doctoral research was done in the laboratories presided over by Dr. Rosa, where a hundred years of basic and empirical electrical research awaited standards and new measurements and the scientists to determine them. Well before the end of the first decade Rosa's had become the premier division of the Bureau.

[93] Annual Report, Research Highlights of the NBS, 1960, pp. 159–160. See also eight-page account of the program attached to letter, L. J. Briggs to U.S. Office of Education, Federal Security Agency, July 12, 1940 (NBS Box 443, ID-Misc).

The brass troy pound of 1758, or Imperial Standard Troy Pound, which with the standard yard of 1760 were declared to be the only original and genuine standards of Great Britain. Both were damaged in the burning of the Houses of Parliament on October 16, 1834.