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The Life and Scientific Contributions of Lyman J. Briggs

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ABSTRACT

Lyman J. Briggs (1874–1963), an early twentieth century physicist at the U.S. Department of Agriculture (USDA), made many significant contributions to our understanding of soil-water and plant-water interactions. He began his career at the Bureau of Soils (BOS) in 1896. At age 23, Briggs published (1897) a description of the roles of surface tension and gravity in determining the state of static soil moisture. Concepts he presented remain central to this subject more than 100 yr later. With J.W. McLane, Briggs developed the "moisture equivalent" concept (a precursor to the idea of field capacity) and a centrifuge apparatus for measuring it. Briggs left the BOS at the end of 1905, under pressure from Milton Whitney, and moved to the Bureau of Plant Industry. Briggs' multi-state experiments with H.L. Shantz on water-use efficiencies showed that in a climate like that of the Great Plains, plants use water more productively in the cooler north than in the warmer south. In 1920, he moved from the USDA to the National Bureau of Standards (NBS), rising to Director in 1933. Among his other contributions to the American scientific community was his leadership, beginning in 1939, of a top secret committee that evolved into the Manhattan Project to develop an atomic bomb during World War II. A life-long baseball fan, Briggs at age 84, studied the speed, spin, and deflection of the curve ball, aided by manager Cookie Lavagetto and the pitching staff of the Washington Senators; he published these findings in a paper in the American Journal of Physics in 1959.

> Roosevelt appointed an Advisory Committee on Uranium…. Its chairman was Lyman J. Briggs, a government scientist who began his career in 1896 as a soil physicist in the Department of Agriculture…. (Hewlett and Anderson, 1962)

So wrote Richard G. Hewlett and Oscar E. Anderson in their 1962 history of the development of the first atomic bomb. A soil physicist in the lead at the inception of the Manhattan Project is not an image that most of us find familiar, but it was the hook that led to this examination of the life and scientific contributions of Lyman J. Briggs.

Lyman Briggs' contributions to soil and plant science are a major part of that story, but the story of Briggs also is one that shows the tremendous growth and character change of American science in the first half of the twentieth century. Briggs was both a product of that transition, and a guiding force in shaping the change. Architect and educator Mario Salvadori has written of the virtue of introducing elements of the history of science as we teach the science itself—the virtue of noting "science's history at every step of its evolution so as to uncover its human dimension and to reduce its abstract nature" (Salvadori, 1997). This virtue too is one of our goals in the telling below.

EARLY YEARS

Lyman James Briggs was born on a farm near Battle Creek, MI on 7 May 1874. He attended Michigan Agricultural College (MAC; now Michigan State University), graduating with a B.S. in Agriculture in 1893. From there, he enrolled in the physics department at the University of Michigan, earning an M.S. in 1895; his thesis research on the electrical conductivity of concentrated sulfuric acid was published in the *Physical Review* (Guthe and Briggs, 1895). For doctoral studies in physics, he chose to attend Johns Hopkins University (JHU). He was in residence on campus for a year, beginning in the fall of 1895. His early research there focused on the newly discovered x-ray (Rowland et al., 1896).

Chronology suggests that romance and the need for a job to support a wife probably played a key role in Briggs' shift to soil physics research. In the summer of

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Abbreviations: BOS, Bureau of Soils; BPI, Bureau of Plant Industry; JHU, Johns Hopkins University; MAC, Michigan Agricultural College; NBS, National Bureau of Standards; PLHI, Plant Life History Investigations; USDA, U.S. Department of Agriculture; USGS, U.S. Geological Survey.

1895, he became engaged to a former classmate from the MAC class of 1893, Katharine Cook. In June 1896, Briggs was hired on a temporary basis as an assistant physicist at the BOS of the USDA in Washington D.C. at a salary of $1400 per year. The BOS Chief, Milton Whitney, immediately was impressed by Briggs, and in September 1896 pushed to have him hired permanently. Whitney had to justify this hiring of Briggs over a candidate who had scored considerably higher on the Civil Service exam. Whitney argued to his superiors that the other candidate was too old (he was 33 yr old), too set in the ways of classical physics, and without a demonstrated interest in practical agriculture. Briggs got the job and was married to Katharine in December 1896 (Records of the Office of the Secretary of Agriculture, 1862-1940; Saunders, 1991).

With permission from Whitney, Briggs was able to pursue his Ph.D. dissertation work as a JHU "Fellow by Courtesy" for the academic year 1900-1901. He traveled from Washington to Baltimore three times a week, and focused his research under Professor Henry Rowland on the adsorption of water vapor and dissolved salts by quartz. In 1901, he received his Ph.D., one of only 20 doctoral degrees awarded in physics in the USA that year (Briggs, 1901, 1905; Astin, 1977; Roman Czujko, personal communication, 2002).

CONTRIBUTIONS TO SOIL AND PLANT SCIENCES

Concepts and Techniques of Soil Physics

In his first year at the BOS, Briggs made a quick shift to soil physics research. At age 23, he published an explanation of the roles of surface tension and gravity in determining the state of soil moisture (Briggs, 1897). In the diagram reproduced here as Fig. 1, he illustrated the flow of water in a porous medium in response to capillary (surface tension) forces alone. Water moves from low-tension, large-curvature regions to high-tension, small-curvature regions. Illustrations like this, with the local radius of curvature of air-water interfaces corresponding inversely to the local magnitude of attractive force, still are common in soil physics textbooks a century later. Less useful today is Briggs' conceptual partitioning of soil water into "gravitation water, capillary water, and hygroscopic water." Gravitation water is free to drain away by gravitational force, capillary water is retained after gravitation water drains away but can move through capillary action, and hygroscopic water cannot move in response to either of these forces. Briggs recognized that these qualitative classifications could not be readily quantified. He noted that the partition between gravitation and capillary water is not an intrinsic property as it depends on the height of the soil sample, and also that "The nature of this thin film which constitutes the hygroscopic moisture is not definitely known." The idea of hygroscopic water, immovable by gravitational or capillary forces, remains today not merely unquantifiable but controversial (Nimmo, 1991; Luckner et al., 1991). Briggs, at that time, did not yet have the quantification of forces that Buckingham's (1907) concept of capillary (matric) potential made possible. It is not obvious to what extent Briggs originated these concepts, but it seems highly likely that he introduced them to Buckingham in 1903, when Buckingham started his own soil physics research under Briggs' supervision. Below we describe in more detail Buckingham's research on this topic, as well Briggs' quantitative experimental work of the 1950s on negative pressures in liquids.

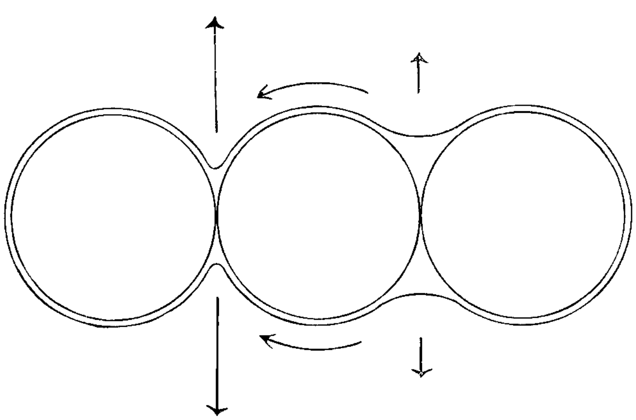

Fig. 1. Diagram of an idealized unsaturated medium that Briggs used in explaining now-familiar concepts of soil-water flow (Briggs, 1897, p. 19). The circles represent spherical soil particles. Water adheres to all solid surfaces. Straight arrows indicate the direction and relative magnitude of capillary force on the air-water interface between particles. The curved arrows show the direction of water flow.

One of Briggs' early experimental efforts at the BOS was to develop a centrifugal method for particle-size analysis (Briggs et al., 1904); this focus on texture probably was influenced by BOS Chief Milton Whitney, who saw soil physical conditions as the primary control on crop production and championed soil texture as the primary soil characteristic to be recognized in soil surveys. The experiments used a low speed centrifuge powered by a desk-fan electric motor.

With J.W. McLane, Briggs later developed a centrifugal method to measure what they termed the "moisture equivalent"—a precursor to the idea of field capacity. Used as a single-number characterization of the water-retaining capacity of a soil sample, the moisture equivalent was defined as the amount of water retained by a soil in capillary equilibrium with a constant centrifugal force of a specified magnitude. Briggs and McLane (1907) centrifuged samples at $3000 \times g$ until the water content approached a constant. Off-the-shelf machines of the early twentieth century were incapable of this task, overheating at the sustained high speeds. Briggs' response illustrated his strong inclination toward mechanical inventiveness; he and McLane developed a new, high-performance centrifuge with special bronze bearings and a specially ground shaft, driven by a steam turbine in an intensively engineered "engine room" adjacent to the laboratory. The centrifuge had to be mounted on a slab that was free from the floor and walls of the building to prevent their vibration or jarring. Edgar Buckingham was connected peripherally to this project, and later became an authority on steam turbines (National Cyclopaedia of American Biography, 1941). This work with Briggs may well have been his introduction to the field. The machine, exclusive of its drive belts and steam engine, and also the centrifuge "head" are shown in Fig. 2. Inside the rotating head are eight soil cups with perforated bottoms to allow water to flow out when the device spins. Later, the definition was standardized operationally as the amount of water retained after centrifuging for 40 min at 1000 $\times$ g. Because in this procedure the matric pressure varies spatially within the sample and is not uniquely determined, the moisture equivalent, like the field capacity (Soil Science Society of America, 1997), cannot be rigorously associated with a specific value of matric pressure.

Briggs and McLane likely did not perceive the importance of the wide variation in moisture that would develop within the soil samples. In the centrifugal field, their 5-mm high samples constituted a physical analog to a 15-m-thick soil profile, which at equilibrium would have a wide range of water contents. Pressure-plate systems, which would have permitted a theoretically sounder and experimentally simpler assessment of water-retaining capacity, were not applied for this purpose until years later. However, the Briggs and McLane method is described thoroughly in the second edition of *Methods of Soil Analysis* (Cassel and Nielsen, 1986). Centrifugal techniques continue to be employed for measurement of soil hydraulic properties, including water retention (Paningbatan, 1980) and hydraulic conductivity (Nimmo et al., 2002).

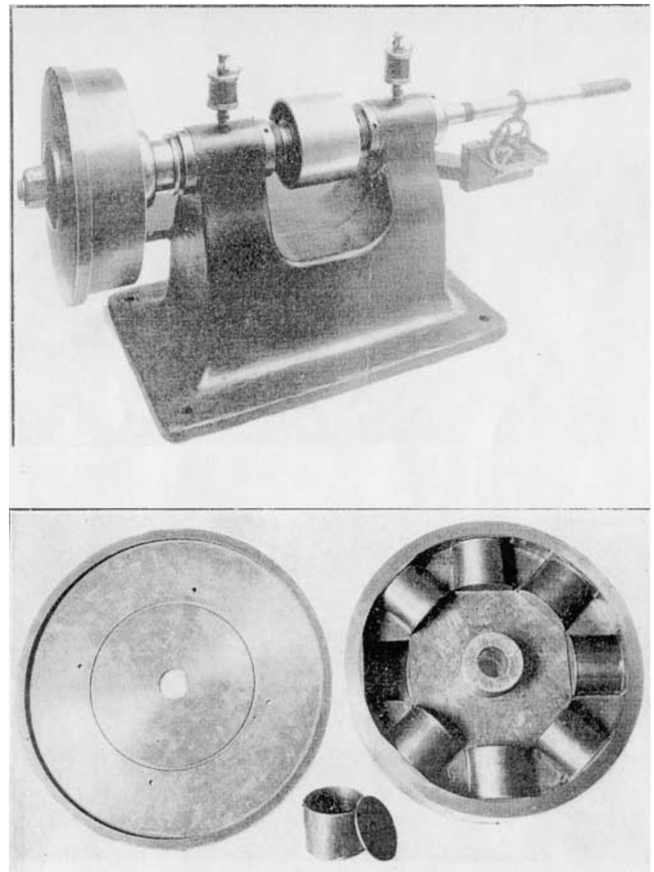

Fig. 2. The centrifuge developed by Briggs and McLane (1907, Plate I) for measuring moisture equivalents. Drive belts not shown here extended into the intensively engineered "engine room" nearby. The centrifuge rotor, or "head," in the lower picture contained eight sample cups with perforated bottoms.

Water Requirement

Working within the USDA Bureau of Plant Industry, Briggs and Plant Physiologist Homer L. Shantz investigated water requirements of plants, with experiments conducted during 1910 through 1916. (Shantz would go on to become the president of the University of Arizona. The building housing the Department of Soil, Water, and Environmental Science on that campus bears his name.) The "water requirement" is the amount of water used per unit dry matter produced (the inverse of the current term for this property, water-use efficiency). Requiring thousands of repetitive measurements on numerous replicates, often over a large geographic scale, studies of this sort were undertaken by several research groups in the early twentieth century, but became far less common after World War I.

The basic plan of the research described above was to grow plants in lysimeters for a wide range of independent variables relevant to plant growth. Among the variables Briggs and Shantz selected for comparative investigation were species, variety, hybridization, geographical location, climate, soil-water content, soil fertility, evaporation, humidity, temperature, seasonality, and frequency of cutting (of grasses). For each combination of variables, Briggs and Shantz typically used six replicates, each of which was a stand-alone lysimeter the size of a household trash can, planted with the desired plants and constructed for control of water input and evaporation. Weighing was done three times a week. The work was very labor-intensive and physically demanding; for example, at one site (Akron, CO) over 500 pots of plants, containing more than 57 000 kg of soil, were used in measurements in 1912. The need for frequent weighing of lysimeters motivated Briggs to pioneer several advances in experimental automation, often incorporating electromechanical inventions, as in the automatic weighing devices of Briggs and Shantz (1915). Some of this equipment and field set-up are illustrated in Fig. 3.

The effects of geography and climate are well illustrated in compiled results of Briggs and Shantz (1917). Table 1, copied directly from this publication, concisely summarizes a large body of data for alfalfa obtained over the summer of 1912 at four stations along a north-south line from Texas to North Dakota. The water requirement varies systematically, increasing steadily from north to south. To produce the same amount of dry matter, in Texas, where evaporation rates are greater, the plants require nearly twice as much water as in North Dakota. The water requirement essentially was directly proportional to pan evaporation, as shown in the last column of Table 1. Although this result carries direct implications that could guide large-scale planning for optimization of agricultural water use, it has not yet

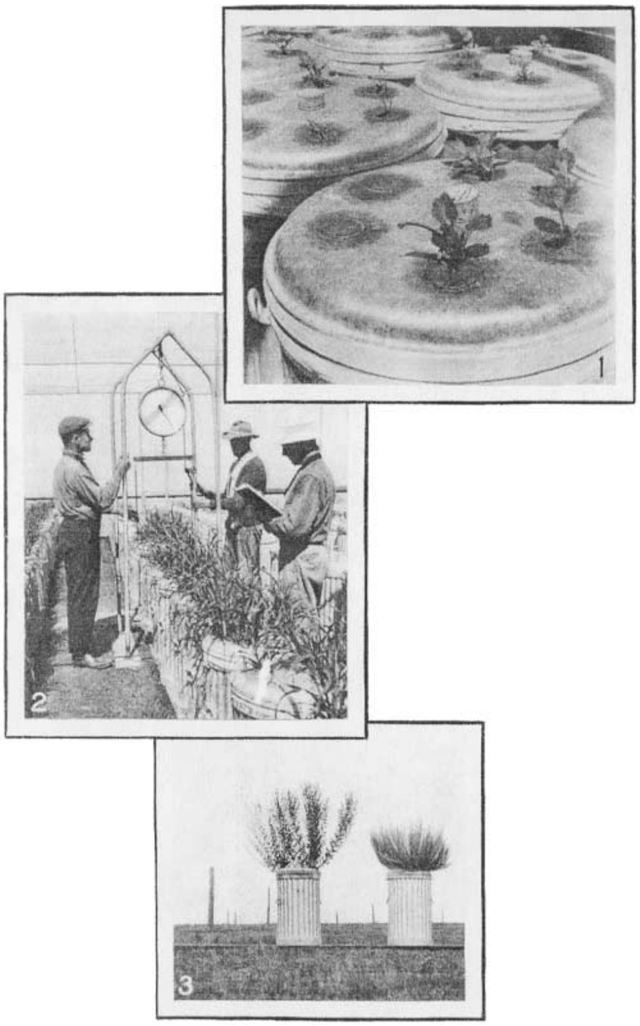

Fig. 3. Collage depicting apparatus for investigating the water requirement of plants (Briggs and Shantz, 1914, Plate II). (1) Lysimeters planted with sugar beets emerging through circular wax seals. (2) The weighing device and its crew of three, who could weigh lysimeters at the rate of 120 per hour. (3) Lysimeters used to study Colorado native plants, gumweed (left), and mountain sage.

been incorporated widely into water law or irrigation practice.

Supervising these field experiments at widely spaced western sites was no easy task. Briggs' files, now at the National Archives, show that he provided the field crews with highly detailed instructions on instrument operation and measurement methods, and that he kept close tabs by telegraph on items such as field experiments when he was at headquarters, and on appropriation bills when he traveled by train to the western sites. In our present era of overnight delivery, it is both confirming and comforting for scientists with field activities to see telegraphed requests from Briggs in Akron, CO back to his laboratory in Washington, requesting that wax, tape, one-hole rubber stoppers, and soldering flux be sent as soon as possible. Likewise, for workers within a bureaucracy, it is a bonding experience to see a 1912 memo to Briggs from the USDA's Division of Accounts and Disbursements telling him that his $109.84 travel reimbursement for a month in the field on these water-use studies has been reduced by 20 cents for carfare in Chicago because he was not authorized to stop there.

Among the interesting peripheral observations made by Briggs during this study was the marked reduction in evaporation at the Akron, CO site within 4 d following a large volcanic eruption at Mt. Katmai in southwestern Alaska on 6 June 1912 (see Briggs and Shantz, 1914, Fig. 1). During the following 4 mo, the "haze of 1912" caused an average reduction in evaporation of about 10% for 15 stations monitored in North Dakota, South Dakota, Montana, Nevada, Utah, Colorado, Nebraska, Kansas, Arizona, and Texas (Briggs and Belz, 1913). Briggs' decision to document these "nuclear winter" observations was indeed well chosen, as the Mt. Katmai (Novarupta) 1912 event turned out to be largest volcanic eruption in the world during the twentieth century.

In connection with their water use studies, Briggs and Shantz (1912) did elegant greenhouse experiments to determine the soil moisture content at which plants wilted. The wilting coefficient measurements involved potted plants for which the soil surface was sealed with a wax-petroleum jelly mixture to prevent evaporation. Provisions were made to provide periodic aeration below the seal, and soil temperature was controlled by means of a water bath. A variety of agronomic and native plants of differing ages, and a range of soils was examined over the course of 3 yr. Ingenious methods were employed for cactus plants, where wilting of tissue was not evident when the soil was no longer able to supply moisture at a rate sufficient to meet the transpiration demand. Here, pots were balanced on knife-edges to separate the load from the moist soil from that of the aboveground plant structures. Moisture shifts from the soil to the aboveground tissues caused the pot to tip, and this movement was monitored. Looking for indirect methods of determining the wilting coefficient, they turned to Briggs and McLane's moisture equivalent. For a series of 17 soils ranging from coarse sand to clay loam, Briggs and Shantz showed the ratio of the $1000 \times g$ moisture equivalent to the wilting coefficient to be 1.84 ± 0.01, thus allowing this physical measurement to be used as a predictor of the lower limit of plant-available water. In a recent review of the emerging

Table 1. Reproduction of Table VII of (Briggs and Shantz, 1917). "Water requirement of the second crop of Grimm Alfalfa at different stations in the Great Plains, 1912." The ratio in the last column was divided by 100 for convenience.

Location	Growth period	Days	Water requirement	Evaporation in inches	Daily evaporation in inches	Ratio of water requirement to daily evaporation
Williston, N. Dak.	July 29-Sept. 16	47	518 ± 12	7.5	0.159	33
Newell, S. Dak.	Aug. 9-Sept. 24	46	630 ± 8	8.6	.187	34
Akron, Colo.	July 26-Sept. 6	42	853 ± 13	9.5	.226	38
Dalhart, Tex.	July 26-Aug. 31	36	1005 ± 8	11.0	.306	34

application of pedotransfer functions in the modeling of water flow and solute transport in soils, Wösten et al. (2001) have noted the pioneering role of Briggs and Shantz (1912) in efforts to bridge data gaps between available soil data, such as particle-size analysis and moisture equivalent, and soil hydraulic characteristics.

Briggs conducted several studies related to electrical effects in soils. His first project on joining the BOS appears to have been the development of electrical resistance methods for the determination of soil moisture (Whitney et al., 1897; Briggs, 1899) and soil temperature (Whitney and Briggs, 1897). This work built nicely on his M.S. thesis work on the electrical conductivity of solutions, and he later expanded on this application to develop an electrical resistance method for the rapid determination of the moisture content of harvested grain (Briggs 1908). Briggs also led experiments testing the efficacy of "electroculture," the controversial practice of improving crop yield by exposing the plant to an electric field or current. The impetus for this work were reports from Russia, communicated to the USDA early in 1904 by the U.S. Consul General in St. Petersburg, on improved crop production associated with electroculture (Adee, 1904). Experimental plots were established in Arlington, VA in 1907, and experiments continued through 1918. Briggs and his collaborators concluded their publication (Briggs et al., 1926) with carefully chosen words. They did not directly choose sides regarding the efficacy of electroculture, but they made clear that the electrical effects on plants are not much greater than the measurement uncertainty. They noted that this had been the general state of affairs in research on this topic as much as 150 yr before their work. Nearly a century after Briggs' work, research continues on this general topic, usually aimed at the issue of whether electromagnetic fields have adverse effects on plants, typically producing results consistent with those of Briggs and the earlier researchers.

Although his focus certainly was physics, Briggs had extensive training at both the University of Michigan and JHU in physical chemistry. He used his chemistry training in a variety of studies at USDA, including investigations of the aqueous chemistry of carbonate salts, with special reference to alkali soils (Cameron et al., 1901), of the role of humic materials in mineral dissolution (Briggs et al., 1916; Jensen 1917), and of potassium availability from orthoclase (Briggs 1917a; Breazeale and Briggs, 1921). He also was interested in using the centrifugal method developed for the moisture equivalent determination to obtain soil solutions for chemical analysis (Briggs, 1907); the method still is in use at present (e.g., Tyler, 2000).

Briggs, Buckingham, and Other Bureau of Soils Colleagues

A less technical, but extremely important contribution of Briggs to soil physics was his organizational role as a senior physicist and assistant chief at the BOS in 1902 when Edgar Buckingham was hired as an assistant physicist. Tanner and Simonson (1993) offer convincing evidence that it was Franklin H. King who recruited Buckingham to the BOS from the physics department at the University of Wisconsin. Briggs and Buckingham had much scientific overlap. They worked simultaneously at BOS and later at the NBS, both times with Briggs higher in the administrative hierarchy and Buckingham more completely focused on physics-based research. In Buckingham's 3 yr on soil physics at the BOS, his achievements include one of the biggest single steps toward the physical quantification of soil-water flow (Buckingham, 1907). Supported by his newly developed theory and experimental evidence, Buckingham introduced the concept of capillary potential (today more commonly called matric potential), as an essential measure of the energy of soil water relevant to flow. After this major advance, Buckingham switched specializations, and the soil science community paid little attention to this contribution for more than 20 yr.

The relationship between Lyman Briggs and Edgar Buckingham has been discussed by Philip (1974, 1988). Philip was highly critical of Briggs for allegedly delaying the publication of Buckingham's Bulletin 38, *Studies on the movement of soil moisture* (Buckingham, 1907). His view of Buckingham was as Briggs' ill-treated subordinate at both USDA and the NBS. The historical record does not support this relationship.

There clearly was no personal animosity between the men, but rather the record suggests a friendship spanning five decades. W.H. Gardner corresponded with Buckingham's daughter, Katharine Buckingham Hunt, then 72 yr old, when preparing his *"Early soil physics into the mid-20th century"* (Gardner, 1986). She reported that the men were personal friends, and that this friendship extended into their families. Buckingham disliked administrative work, and when Briggs was his superior, he appears to have sheltered Buckingham from such duties, only delegating such tasks to him when Briggs was away. At the NBS, Buckingham worked as a part-time consultant to the Engineering Physics Division (later reorganized as the Mechanics and Sound Division) headed by Briggs from 1923 to 1937 (Cochrane, 1966, p. 592). However, during this same time period, he enjoyed the rare and coveted status of independent researcher, free from all administrative duties to pursue his work on theoretical thermodynamics. Buckingham retired in 1937 and died in 1940; he was the first NBS scientist to be granted independent status, and only one of three to be given it during the 1923-1937 period (Cochrane, 1966, p. 147). The acknowledgment in Briggs' World War II monograph on the coefficient of restitution and spin of baseballs and golf balls closes with "to the late Edgar Buckingham for his constructive suggestions."

Of Buckingham's Bulletin 38, Philip (1974) writes:

> The paper was not published until 1907, two years after Buckingham had moved on (to NBS) and a year after Briggs had gone to his new post in the Bureau of Plant Industry. The letter of transmittal, and the preface, omitted the usual acknowledgment of the author by name; and there was no hint of approval from the author's superior (Briggs).

A delay of 2 yr in the publication of a U.S. government scientific report is certainly not unusual today, nor probably in 1905. However there is no evidence that a delay in publication of even a few months occurred. Documents available at the National Archives in College Park, MD show that Buckingham did not resign from USDA until August 1906, and did not complete his final revisions of the manuscript until November 1906; the report was published in February 1907. Other archived documents show that the period from August to December 1905 was a time of tremendous turmoil for Briggs in particular, and for soil physics research in general at the BOS (Records of the Bureau of Soils, 1907-1927; Records of the Biophysical Laboratory, 1907-1920; Records of the Office of the Secretary of Agriculture, 1862-1940).

After his hiring by Whitney in 1896, Briggs received promotions in 1898 (to assistant chief of the Bureau) and 1901 (from assistant physicist to soil physicist), and a 25% pay increase in 1902. Lyman Briggs appeared to be on a successful career path at the BOS. Then, in August 1905, the Chief of the BOS, Milton Whitney, sent a seemingly routine request to his staff. The Secretary of Agriculture had sent a request to all bureaus requesting information on outside work and commercial interests of USDA employees. Briggs replied on 25 Aug. 1905, noting a series of papers he was preparing outside of work time on soils, manures, and fertilizers for the Columbian Correspondence College of Washington D.C. (he was to be paid $300 for their preparation and revision over the next 4 yr), and plans for a series of lectures on "practical electricity" that he was going to give in the evenings during the winter of 1906 at the Y.M.C.A. in Washington D.C. By the next day Briggs had a strongly worded, three-page reply from Whitney in which he used the outside work question as a springboard to far bigger issues. Whitney wrote:

> While I have always recognized your training and ability, I have felt that perhaps our problems are so difficult that they could not be treated in the strictly mathematical way in which your training has induced you to look upon them and that you are wasting your time and ability in the Bureau of Soils. I have, as you know, several times…*{not readable}*… advised you to find a position…*{not readable}*… use your training to better advantage than you have done here.

Whitney also complained that Briggs' "relations with the other men of the Bureau have not been cordial and helpful," that Briggs had failed to make the laboratory of soil physics a more useful part of the Bureau, and of Briggs' interests "in lectures, in cooperative work with other Bureaus in the Department, with the Carnegie Institution and with other Departments."

On 28 Aug. 1905, Briggs sent back a four-page reply defending his work, his relations with coworkers, and his outside activities. He wrote:

> I can only regret that it has appeared to you that my attention has been given 'more and more to outside problems or to outside persons.' These relations have seemed to me highly desirable as the best means of gaining other points of view, which appear to me necessary in order to maintain the work of our Bureau along the lines of largest practical and scientific value.

In elaborating on his cooperative efforts with other USDA and academic colleagues, Briggs complained that a 3-wk trip with Professor Chilcott (presumably agronomist E. C. Chilcott of South Dakota Agricultural College and later the Bureau of Plant Industry of USDA) in connection with investigations on cultivation methods in the High Plains region afforded him the only opportunity to study soils under field conditions during his 9 yr at the BOS; his other field time being allegedly being limited to two 3-d trips.

Steps quickly were taken to have Briggs transferred to another part of USDA, either Plant Life History Investigations (PLHI) group (of the Office of the Secretary of Agriculture) where plans were underway for a study of the effects of electricity on plant growth, or to the Bureau of Plant Industry (BPI). On 2 Sept. 1905, Whitney would write:

> …. that Mr. Briggs could do much better there *(PLHI)* than he has been able to do in this Bureau, for the subject of soil physics is not capable at the present time of the rigid mathematical demonstration which Mr. Briggs through his training can only give. We have to depend on more crude methods of experimentation to formulate first approximate facts and laws before we can ever hope to apply rigorous mathematical physic measurments *(sic)*.

One can imagine how these words impacted Edgar Buckingham. Unlike Briggs who held a bachelors degree in agriculture, Buckingham was trained solely as a physicist and his expertise was in thermodynamics. In 1904, his colleague from Wisconsin, F.H. King, was dismissed by Whitney. In 1905, Buckingham was completing his pioneering treatise on the equilibrium and flow behavior of soil water (Sposito, 1986). Edgar Buckingham was the number two person in the soil physics laboratory, and the criticism heaped on his laboratory chief and friend Lyman Briggs could not have escaped him. Of the two soil physicists, the rigorous mathematical treatment so disliked by Whitney best described Buckingham's work.

By 9 Sept. 1905, a deal had been cut sending Briggs to the BPI. A new project, headed by Briggs and focusing broadly on designing instruments and methods to investigate the relation of physical factors to crop production, was agreed to in November 1905. By 1 Jan. 1906, Briggs' transfer was completed, and BOS soil chemist Frank K. Cameron was made temporary head of the laboratory of soil physics; Edgar Buckingham remained as assistant physicist. When Buckingham resigned his position with the BOS on 14 Aug. 1906, he moved to the Department of Commerce's Bureau of Standards, also in Washington D.C., where he would spend the next 30 yr. Cameron, not Briggs, was Buckingham's supervisor at this point, and Cameron and Whitney, not Briggs, handled the final editing of Bulletin 38. During the next 6 mo, Buckingham argued with Cameron over his contention that Buckingham's theory fundamentally was flawed, and with Whitney over two concluding paragraphs that were omitted at Whitney's insistence. Despite these disputes, all parties moved the paper expeditiously to publication in February 1907 (Nimmo and Landa, 2001).

Briggs at Bureau of Plant Industry

Briggs enjoyed what appears to be a productive and harmonious period from 1906 to 1919 as a BPI research leader. The first annual progress report by Briggs to the BPI (December 1906) reiterated the position he took with Whitney a year earlier: "The Physical Laboratory has been working in close collaboration with a number of other offices in the Bureau and it is believed that these cooperative relations will result in well rounded investigations." When he resigned from the BPI on 1 Dec. 1919, and moved permanently to NBS, his letter to the BPI chief noted:

> I do not recall a single instance during all these years of any serious difference of opinion or policy in connection with the work entrusted to me, or anything but the most cordial relationship. I wish to tell you at this time how much I have appreciated the confidence you have imposed in me. (Records of the Biophysical Laboratory, 1906-1920.).

When interviewed in 1962, Briggs gave no hint of his stormy relations with Whitney, but noted him along with Eugene W. Hilgard and Franklin H. King as the three pioneering American soil physicists at the turn-of-the twentieth century (Cochrane, 1962, p. 313).

The management at BPI seems to have been open to scientific collaboration with other agencies and excursions outside of the mainline agricultural studies, undoubtedly a relief to Briggs after his censure by Whitney. At the request of the Office of Public Roads, Briggs developed an electrical device to measure the speed of cars over measured courses more accurately than could be done with an ordinary speedometer. The device was needed for road surface abrasion studies, and Briggs' testing used a variety of vehicles, including a Fiat racing car that traveled the 0.10-mile test track at 76.7 miles per hour. His report to the Office of Public Roads concluded by noting that the new speed-recording device, which could measure travel times accurately within 0.02 s, would be of great value in athletic events such as the 100-yard dash:

> This can be run in about 10 second. The smallest interval of time that can be measured by a stop watch is one-fifth of a second, so that the stopwatch is incapable of measuring time intervals more closely than would be represented by a space interval of two yards between the contestants at the finish. This sport manifestly deserves a more refined measurement of time intervals than is possible with stop watches. (Briggs, undated)

This work would prove to be the first of Briggs' several forays into the physics of sports.

Another diversion from his mainline studies at BPI occurred in 1914 and 1915. Briggs devised a new method of measuring the acceleration of gravity at sea and made measurements during voyages in 1914 from San Francisco to Sydney, Australia, and in 1915 from New York to San Francisco via the Panama Canal (Briggs, 1916). His trip from Washington to San Francisco in 1914 served double duty in both carrying out the water-use studies en-route, and getting him to his ship. He received a grant from the Australian and New Zealand governments in connection with his attendance at a meeting of the British Association for the Advancement of Science to make the 1914 voyage. The trip back from Sydney was moved up by a week because of the outbreak of World War I in Europe, and involved a blackout run for most of the trip because of fear of interception by the German navy (Saunders, 1991). The second voyage was funded by the American Association for the Advancement of Science.

WORK AT NATIONAL BUREAU OF STANDARDS

When the USA entered the War in 1917, the NBS requested that Briggs be detailed there for the duration of the war to work on topics of interest to the Aviation Section of the Signal Corps. This was done by Executive Order from the Office of the President, with the further stipulation that the facilities of his Laboratory of Biophysical Investigations at the BPI be placed at the disposal of the NBS for construction of apparatus and other technical assistance (Records of the Biophysical Laboratory, 1906–1920).

Briggs' wartime work at NBS involved the design and construction of a wind tunnel for aerodynamic research, and the development of a "stable zenith" device, a gyroscopic instrument for maintaining an artificial horizon to aid in directing fire for large guns on naval vessels. A wind tunnel with air speeds approaching the speed of sound was built. The wind-tunnel work for the Army Air Service involved improving propeller designs. Briggs' machinist from his USDA laboratory, W.H. Cottrell, came over to NBS and did instrument building for him on this project and others for many years (Briggs et al., 1925). For the gunnery work, Briggs' experience with vibrating, rolling, and pitching ships at sea gained during the gravity experiments was undoubtedly of great value (Briggs, 1922). The device designed by Briggs and coworkers was tested aboard the battleships *U.S.S. Arizona* and *U.S.S. Mississippi* in October 1918 (Records of the National Institute of Standards and Technology, 1907–1962). The work was highly classified and continued until 1921 when the device was turned over to the Navy. The Navy went on to add these instruments to all of its battleships (Records of the National Institute of Standards and Technology 1907–1962). When interviewed by a *Washington Star* journalist in 1954 for an article on his 80th birthday (Rodgers, 1954), Briggs discussed the wartime testing of the stable zenith device on a battleship in an area patrolled by German submarines. His coworker was apprehensive about being in the combat zone, and asked the captain what his lifeboat assignment would be if the ship went down. As Briggs recalled: "I thought I detected a flicker of the captain's eyelids as he sent a man to find out. The sailor returned and saluted and said, 'Sir, the C.O. said his assignment will be in lifeboat No. 4 on the second trip.'"

World War I ended but Briggs' work was in great

Fig. 4. Photo of Briggs in 1933 when he was appointed Director of the National Bureau of Standards.

demand by the Army and Navy, and therefore he resigned from the USDA in 1919. Among his other notable scientific achievements in the coming years was the design, with Paul R. Heyl, of an aircraft compass (Heyl and Briggs, 1922) that was used by Charles Lindbergh in his transatlantic flight and by Admiral Richard Byrd on his flight to the North Pole. Briggs' administrative talents also were recognized. He rose through the ranks to become the Director of NBS in 1933 (Fig. 4), and guided the agency through the difficult Depression and World War II years.

ATOMIC BOMB

> When the world's supply of coal and oil is exhausted, man will be reduced to the extremity of dependence upon solar engines, water power, and wood as sources of energy, unless his ingenuity has meantime been equal to the task of liberating the energy of the atom. (Briggs, 1917b)

In the closing of a 1917 paper on plant growth and plant biomass as food and fuel, Briggs, the physicist, hauntingly would note the potential for nuclear power and nuclear weapons (Briggs, 1917b). What could not be foreseen was the role he would play in this arena.

On 11 Oct. 1939, Albert Einstein's famous letter on the potential for a chain-reaction weapon was given to President Franklin D. Roosevelt (White Sands Missile Range, 2002). Einstein wrote:

> In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence who could perhaps serve in an unofficial capacity. His task might comprise the following:
> a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problems of securing a supply of uranium ore for the United States.
> b) to speed up the experimental work, which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the cooperation of industrial laboratories which have the necessary equipment.

For the task that Einstein outlined, the President turned to the senior physical scientist in the government, NBS Director Lyman Briggs. The Uranium (or S-1) Committee, headed by Briggs, reported back to the President on 1 Nov. 1939. It affirmed the need to move ahead with the immediate purchase of uranium oxide and graphite for experimental use. The race for the atomic bomb was on.

Briggs was a physicist but acknowledged that he was not a nuclear physicist. One of his early sources of information was Phillip H. Abelson, who was working in a laboratory at the NBS as a guest investigator from the Carnegie Institution. Abelson, who had recently completed his Ph.D. with Ernest O. Lawrence at Berkeley, was looking at the separation of uranium isotopes using liquid thermal diffusion. (Abelson's research supervisor Merle Tuve earlier had asked Briggs to provide the space to avoid contamination of low-level counting facilities at the Carnegie.) The process that he began developing at NBS was the one eventually selected for enrichment of ^{235}U in the Manhattan Project. Later, on the eve of the celebration of Briggs' 80th birthday, Abelson, then the Director of the Geophysical Laboratory of the Carnegie Institution, would write:

> The crucial role played by Dr. Briggs and the S-1 Committee is a story that has never been properly told. The present multi-billion dollar program of the Atomic Energy Commission has its roots in a series of remarkably wise decisions made in 1940. (Abelson, 1954).

In a recent conversation with Dr. Abelson, now Editor Emeritus of the journal *Science*, he remembered Briggs fondly as a "completely honorable" man (P.H. Abelson, personal communication, 2000).

Briggs approached the unknown territory of a nuclear fission weapon with caution. His deliberate pace angered some of the leading scientists involved, including E.O. Lawrence, I.I. Rabi, and Leo Szilard. His leadership role on the project was eroded and gradually phased out by mid-1942 (Fig. 5), although he remained part of the technical oversight group through at least the fall of 1943 (Hewlett and Anderson, 1962; Rhodes, 1986; Leslie, 1990; Passaglia and Beal, 1992).

An interesting sidelight to this chapter of Lyman

Fig. 5. Lyman Briggs at a 13 Sept. 1942 meeting in Bohemian Grove, CA of the S-1 Executive Committee which constituted the scientific leadership of the American atomic bomb project. Left to right: Harold Urey, Ernest Lawrence, James Conant, Briggs, Edgar Murphee, Arthur Compton. (Credit: Ernest Orlando Lawrence Berkeley National Laboratory, courtesy AIP Emilio Segrè Visual Archives).

Briggs' life involved his grandson, Peter Briggs Myers. On a day in September 1942, the 16-yr old Peter was canoeing on Saranac Lake, NY. The weather turned bad, and he spotted a lone man in a small sailboat having great difficulty lowering the sail. Peter paddled along side and helped to bring the sailboat safely to shore. He immediately recognized the lone sailor as Albert Einstein. At Einstein's cottage, the two men dried out and spoke. Peter Myers mentioned his physicist grandfather. Yes, Einstein said he knew him, but the connection—the secret Manhattan Project—was, of course, never mentioned. Peter went on to become a Rhodes Scholar at Oxford, earning a doctorate in physics in 1950 (Saunders, 1991; Peter Briggs Myers, personal communication, 2001).

LATER YEARS

Briggs retired in 1945 at age 71. He returned to his laboratory work at NBS. Described then as "frail and tired" from the pressures of directing a wartime NBS (Cochrane, 1966), he seems to have been reinvigorated by his newfound freedom as an emeritus research scientist. In a notable facet of his post-World War II work, Briggs returned to the subject of negative pressures. The central issue he explored now was how great a magnitude of negative pressure a liquid can sustain. The existence and interpretation of such negative pressures relates to ideas that Briggs had been acquainted with since at least 1897 (Fig. 1), and is related directly to Buckingham's concept of capillary potential. Briggs conducted experiments on various substances including mercury and chloroform, but of primary importance to soil physics, he studied water (Briggs, 1950). The basic method of these studies was to apply force that tends to pull apart a continuum of liquid in a tube, increasing the force to decrease pressure within the liquid. When intermolecular forces are sufficiently exceeded somewhere, cavitation occurs, that is, a vapor phase is created that immediately expands and breaks the continuity of the liquid mass. Briggs used a centrifuge and liquid in a tube that was horizontal in the plane of rotation so that centrifugal force would pull liquid outward toward both ends, creating a calculable negative pressure at the center. For experiments on water, the tube was open at both ends and cleverly bent into a Z-shape that held the liquid centrally as long as it remained a continuous phase. At a sufficiently high speed of rotation, cavitation would occur and the centrifugal force immediately would drive the water out of the tube. Briggs found that with adequate attention to experimental details and cleanliness, the liquid could sustain without cavitation negative pressures far exceeding the magnitude of atmospheric pressure. For liquid water, he established negative pressures as great as 277 bars (27.7 MPa), and showed that the magnitude of this limiting pressure declines drastically at temperatures below 5°C (Fig. 6). This added the limiting negative liquid pressure to the list of properties that are anomalous in water at such

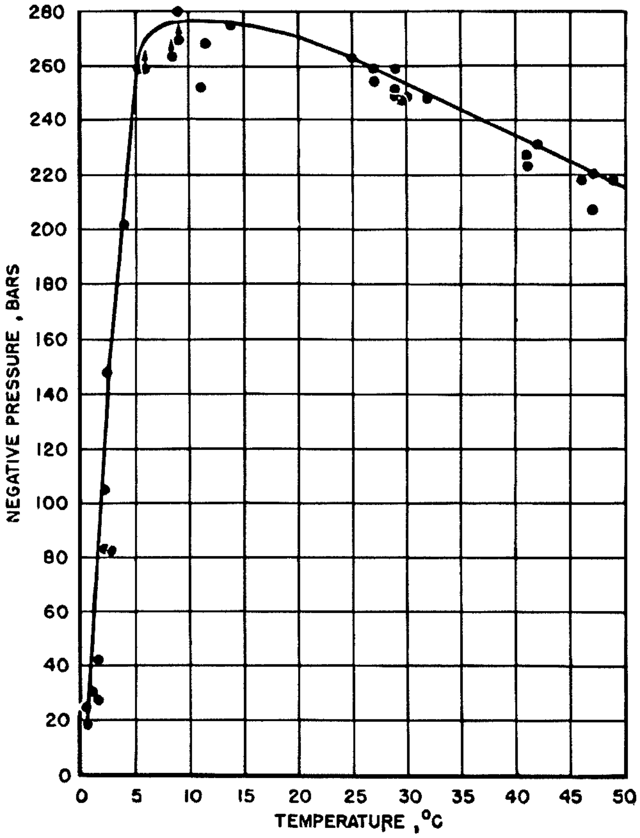

Fig. 6. Briggs' (1950, p. 721) measurements of the limiting negative pressure of water, as a function of temperature. These results show that liquid water can sustain negative pressures as extreme as 28 MPa (280 bars) and that the temperature dependence of this limiting pressure is anomalous, like many other properties of water, within a few degrees Celsius of the freezing point.

temperatures. Between 1950 and 1957, Briggs published seven sole-author journal articles on negative pressure in the *Journal of Applied Physics* and the *Journal of Chemical Physics* (Briggs, 1950, 1951, 1953a, 1953b, 1955a, 1955b, 1957a).

Implications and conclusions from the work described above are of considerable significance, and research on limiting negative liquid pressures continues as an active field of physics (e.g., Maris and Balibar, 2000). Now, as in Briggs' day, results meet with skepticism when interpreted with an unwarrantedly strong analogy to an evacuated space where the absolute pressure cannot be reduced below zero. Among soil physicists today, the existence and interpretation of such negative pressures remains a subject of ongoing controversy (e.g., Gray and Hassanizadeh, 1994; Miller, 1994). It must have been extremely satisfying for Briggs to combine centrifuge techniques with negative pressure concepts, both of which were major themes of his early career, but which he had done little work with for nearly 50 yr. Moreover, his successful return to laboratory experimentation produced results that were both startling and important.

During 1947 until 1948, Briggs directed a major eclipse study by the National Geographic Society (Grosvenor, 1954; Briggs, 1957b). In 1954, there was a major celebration of his 80th birthday, with a special issue of the American Association for the Advancement of Science "Scientific Monthly" magazine (including a paper "The measurement of soil water in relation to plant requirements" by Lorenzo A. Richards [1954]), and a luncheon at the Cosmos Club in Washington, D.C. in his honor. Still the soil physicist, Briggs (1954) told his audience that the recipe for reaching this age was to pick your ancestors well, to not smoke, and to arrange your work "so as to try to avoid, if possible, working under pressure. This is very important and in my case, I have succeeded in working under negative pressure."

Briggs' successor as NBS Director was another prominent physicist, Edward U. Condon. Early in 1948, Condon was attacked by the House Committee on Un-American Activities as "one of the weakest links in our atomic security." President Truman remained a firm supporter of Condon (Wang, 2001), and apparently so did Lyman Briggs. In an obituary for Briggs, Condon (1964) wrote:

> He was a man of unfailing courtesy, kindness, tact, and consideration. We shall never know the complete story of the many ways in which he helped others scientifically and in their personal relationships. His friendship was a source of great encouragement to me during the difficult days of the persecution of scientists by the late Senator McCarthy and other politicians, which did so much to damage the careers of able scientists, and added so greatly to the difficulties of the federal government in recruiting good men into its service.

Baseball was an important part of the life of Lyman Briggs. He played outfield for Michigan State and often quoted famed Negro League pitcher Leroy "Satchel" Paige. As Director of NBS, he is said to have kept these quotes under glass next to the organizational chart of the Bureau (Cochrane, 1966). During World War II, at the request of the War Department and the American and National Leagues, he did tests of the liveliness of baseballs with cork versus rubber centers—rubber being rationed because of wartime shortages. He concluded that "a hard-hit fly ball with a 1943 center might be expected to fall about 30 feet short of a prewar ball hit under the same conditions" (Briggs, 1945). His report on the performance of baseballs also included the results of his 1929 investigations on the liveliness of golf balls, requested by the U.S. Golf Association; allegedly livelier golf balls were causing hardships for owners of small golf courses.

In retirement, Briggs' attention shifted to baseball's curve ball and the question: Did it really curve, or was this an optical illusion? Wind tunnel studies by Briggs showed that a spinning ball really was deflected. But how much spin was there on a curve ball? For this question, Briggs went to Griffith Stadium and the 1958 Washington Senators. With the help of manager Cookie Lavagetto and pitchers Pedro Ramos and Camilo Pascual (both pitchers on the All-Star team the following year), Briggs determined the spin of a curve ball by using a flat ribbon tied to a baseball (the ball-ribbon set used is preserved at the National Institute of Standards and Technology Museum in Gaithersburg, MD).

After the pitch was thrown the 60 feet from the pitchers mound to home plate, the number of twists in the ribbon was counted. The press loved the story of the 85-yr old "atomic scientist"—stories headed "Physicist has ball for himself," "Curve now has government approval," "Dizzy Dean right: it ain't no optical illusion for batters!", and "Lavagetto cooks up pitches for science" (Science Service, 1959) abounded in the newspapers of March-April 1959. The official press release from the NBS (1959) stated: "The serious purpose of the study is to determine the relationship of spin to deflection at different speeds. The problem has applications to ballistics at very low speeds." When interviewed in 1962, Briggs indicated he did it mostly "for the fun of it" (Cochrane, 1962). He published his findings in the *American Journal of Physics* (Briggs, 1959). His paper is still cited today as one of the seminal works on the physics of baseball (Adair, 1990).

While our focus here is on Lyman Briggs, we would be lax not to mention his remarkable family. His wife, Katharine Cook Briggs, was a gifted writer whose attention later shifted to the study of personalities. She corresponded with noted Swiss psychiatrist Carl Jung, and did her own research on methods of assessing different personality types. Katharine and daughter Isabel Briggs Myers went on to develop the Myers-Briggs Type Indicator, first published by the Educational Testing Service in 1959, and since translated into 16 languages (Saunders, 1991). Initially known only within the psychological community, the Myers-Briggs test is now familiar to many because of its widespread usage in workshops and seminars focused on workplace-, family-, and dating-interpersonal dynamics.

A LIFE OF SCIENCE AND PUBLIC SERVICE

Lyman James Briggs died on 25 Mar. 1963, remaining active until the last year of his life. He began his career in an era when the American scientific community was small and tight-knit. Science within the U.S. government then was centered largely in Washington, D.C., and was performed at the Smithsonian Institution and just three executive agencies–the USDA, the BOS, and the U.S. Geological Survey (USGS). Briggs and colleagues would gather in the evening at the Cosmos Club, or at the home of Alexander Graham Bell, to exchange ideas. Briggs was an early champion of federal support of basic research in chemistry, physics, and engineering, both within government laboratories and through support of research in universities (Pursell, 1968). While his efforts to this end in the late 1930s did not lead to the establishment of any specific programs, the atomic bomb development program that he guided at its inception ushered in the beginning of big-scale science efforts funded by the federal government; for example, the man on the moon, the human genome. By training, position, and administrative skills, Briggs moved comfortably in the circle of the top physicists of the day—Millikan, Urey, Oppenheimer—and provided a link between the academics and the government officials during the early days of the Manhattan Project.

Throughout his life, Briggs maintained a gentleness and grace that shows through in the many tributes written for the celebration of his 80th birthday and on his death. The breadth of his scientific interests and contributions, the longevity of his scientific career, and his ability to succeed as both a scientist and research administrator were exemplary and unique. A sundial commemorating his service now resides in the atrium of the headquarters building of the National Institute of Standards and Technology Library in Gaithersburg, MD. In 1967, his alma mater, Michigan State University, named its newly founded undergraduate, residential college focusing on the sciences, the Lyman Briggs College (now the Lyman Briggs School). While best known now in the annals of American science for work in other fields, we take note of the fact that his professional career began and ended with contributions to soil science.

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