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George C. Caldwell (1834-1907): American Agricultural Chemist

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Pat Munday, PhD
Professor of Science & Technology Studies
Montana Tech of the University of Montana
Butte MT 59701

Contact information: pmunday@mtech.edu

Abstract

George Caldwell served as president of the American Chemical Society (ACS) in 1892. Prior to this time, the ACS had been a rather parochial New York City based organization. In 1890, the constituency of the ACS expressed its desire to become a truly national body. Toward this end, it forged closer ties with the Chemical Section of the American Association for the Advancement of Science (AAAS), and merged with the Chemical Section in 1891. As Caldwell had been active with the AAAS group for several years previous to this merger, his election to the presidency of the ACS can be seen as an expression of unity in the American chemical community.

Like most 19th century American chemists, Caldwell's professional life was focused on institution building and teaching, and he made few original contributions to science. He earned his PhD from Wöhler at Göttingen in 1857 and, with high hopes for launching a career in agricultural chemistry, he returned to the United States. Over the next ten years, Caldwell met with a number of misfortunes in reaching this goal. Positions at Columbia College and at Antioch turned out to be disappointing at best, and during the Civil War he served with the U.S. Sanitary Commission. Following several more disappointing years at the Pennsylvania

[1] This paper was originally presented as an invited paper for the "Cachet Series on Past Presidents" at the 1991 meeting of the American Chemical Society in Atlanta, Georgia. It has been revised and expanded since that time. The author thanks Scott Juskiewicz, Kristi Carroll, and other Montana Tech Library administrators and staff for helping make this research and publication possible.

Agricultural College, Caldwell began his life's work with the newly established Cornell University.

George Caldwell taught at Cornell for more than 30 years. His teaching load was heavy, often entailing four or more courses per semester. To supplement his meager salary, he worked for the state board of health, and his wife took boarders into their home. Over the years, Caldwell's various administrative duties included serving as dean of the agricultural college and as director of the agricultural experiment station. He was instrumental in forging close ties between the agricultural college and the farmers of New York State.

Caldwell's chemical philosophy centered on analytical methods. After his retirement, several Cornell professors of chemistry felt that Caldwell leadership had caused the department to "fall behind" in fields such as industrial and physical chemistry. Despite this criticism, Caldwell also left a positive legacy, a legacy best seen in the work of his student Cyril G. Hopkins. Hopkins' work on the chemistry of the corn kernel is classic, as is his "ear-to-row" method of line breeding. Furthermore, Hopkins' students carried this legacy of organic analysis still further with their work on vitamin chemistry.

Land Acknowledgement

Cornell University is located on the traditional homelands of the Gayogo̲hó꞉nǫ̀ʔ, also known as the Cayuga Nation. Cornell received nearly one million acres from more than 230 Indigenous Tribes in fifteen different states.The Gayogo̲hó꞉nǫ̀ʔ are members of the Hodino̲hsǫ́꞉nih Confederacy, an alliance of six sovereign Nations with a historic and contemporary presence on the lands of what became New York State. The Confederacy long preceded the establishment of Cornell University, New York state, and the United States of America. Cornell University was the largest single beneficiary of the Morrill Act of 1862, which expropriated tribal lands from Native Communities to fund the new land grant universities. I acknowledge the painful history of dispossession from the Gayogo̲hó꞉nǫ̀ʔ and other peoples, and honor the ongoing connection of Gayogo̲hó꞉nǫ̀ʔ people, past and present, to the lands and waters of the Finger Lakes region.

George C. Caldwell (1834-1907): American Agricultural Chemist

George Caldwell's life is a story of the slow and steady establishment of a secure institutional foundation for chemistry and agricultural science in America. Like Samuel W. Johnson[2] (1830-1909) and Evan Pugh (1828-64), George Chapman Caldwell was one of the many American farm boys who followed the lead of Eben Norton Horsford (1818-93) and went to Europe to study the new agricultural chemistry.[3] They visited various centers where the new science was being developed, and they brought to the United States the influences of renowned chemists including Justus von Liebig, J. B. Boussingault, and James F. W. Johnston. Like the others, Caldwell travelled throughout England, France, and the German countries, visiting chemical laboratories and experiment stations, and getting to know those chemists who were at the very cutting edge of science.[4] The Americans integrated these various influences and went on to found

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[2] S. W. Johnson authored several classics in agricultural science, *How Crops Grow* (1868-1911, 14 editions) and *How Crops Feed* (1870-1910, 8 editions), during his lifetime as a professor at Yale University.

[3] Margaret W. Rossiter, *The Emergence of Agricultural Science: Justus von Liebig and the Americans, 1840 - 1880*. (New Haven: Yale University Press, 1975). Includes chapters on Eben Norton Horsforsd, John Pitkin Norton, and Samuel W. Johnson.

Pat Munday, "Eben Norton Horsford" (biographical entry), John A. Garraty and Mark C. Carnes, ed.s, *American National Biography* (Oxford University Press): vol. 24, pp. 227-228.

Jacqueline M. Bloom, "Evan Pugh: The Education of a Scientist, 1828 - 1859," unpublished M.A. thesis, Pennsylvania State University, Department of History, 1960. Bloom does not resist the tempatation to glorify the moral character of young Pugh. I thank Dr. M. W. Rossiter for kindly bringing Bloom's work to my notice. See also the recent authoritative biography of Pugh, Roger L. Williams, *Evan Pugh's Penn State: America's Model Agricultural College* (University Park, Pennsylvania: The Pennsylvania State University Press, 2018).

On the advanced state of the agricultural sciences in the German states during this period, see Ursula Schling-Brodersen, *Entwicklung und Institutionalisierung der Agrikulturchemie im 19. Jahrhundert* (Technische Universität Braunschweig, 1989).

[4] Paul R. Jones, "Contrasting Mentors for English-Speaking Chemistry Students in Germany in the Nineteenth Century: Liebig, Wöhler, and Bunsen", *Bulletin for the History of Chemistry* 37 (no.

their own schools of chemistry, often within the land-grant colleges that sprang up after the Civil War.

S. W. Johnson authored several classics in agricultural science, *How Crops Grow* (1868-1911, 14 editions) and *How Crops Feed* (1870-1910, 8 editions), during his lifetime as a professor at Yale University. Evan Pugh, an orphaned Quaker boy, worked himself through school to prepare for his doctoral work in Germany. Once in Germany, he registered moral indignation over the German's drinking habits and at the repressive political situation there. Upon graduating, he helped to solve a major scientific controversy between two eminent French chemists, Boussingault and Ville. Before his short life ended, he molded the floundering Farmer's High School into the Agricultural College of Pennsylvania (now The Penn State).

Caldwell was the only son born to a Farmington, Massachussetts preacher. He was reared on the family farm in Lunenburg, Massachussetts, and this farm upbringing may have helped sway him to take up agricultural chemistry. Certainly it left an indelible mark on his character. After he returned from Europe, it was with great regret that George Caldwell assented to his father's decision to sell the family farm.[5] Later still, at a low point in his professional career, Caldwell longed to return to the farming life. It was at this time that he seriously considered buying a farm property and turning away from academia. But he stuck by his chosen profession, and as a faculty member of the Cornell University College of Agriculture, he worked successfully to forge ties between the university and the farmers of New York State.

Caldwell's career as a chemist divides roughly into three stages. The first, from 1851 to 1857, consisted of his education at the Lawrence Scientific School of Harvard University and at

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1): 14-23. In addition to characterizing the mentoring styles, Jones reinforces the point that chemistry as an academic discipline was virtually non-existent in early 1800s United States.

[5] Diary of G. C. Caldwell, 23 February 1864, 14/8/271-box 2, Caldwell Collection, Department of Manuscripts & Archives, Cornell Unversity Libraries, Ithaca, NY 14853.

several German universities. The second stage, from 1858 to 1868, was a series of disappointments. Caldwell discovered he could not merely model his career after those of the men he had studied with in Europe. Science in the United States was very unlike the intitutionalized science he had become familiar with in Europe. One could say fairly that science in America did not yet exist, a history that Caldwell himself recounted in his 1892 Presidential Address to the American Chemical Society.[6] Once he realized this, Caldwell entered into the third and final stage of his career, devoting himself to the various aspects of institution building that were necessary to make science in America a reality. The highpoint of Caldwell's career came in 1892, the year he was named president of the American Chemical Society.

Education

Caldwell took his B.S. from the recently established Lawrence Scientific School of Harvard University in 1855. In antebellum America, higher education hardly deserved the name. Romantic illusions aside, American universities of this era were mean and dull places. The faculty was drawn from the elite stratum of society, for only the independently wealthy man could afford to be a professor. Teaching consisted of unimaginative rote memorization and drill, and students were held accountable to no standard. In the sciences, laboratory facilities were inadequate for the faculty, and virtually nonexistent for students. Despite these bleak circumstances, Caldwell did encounter two positive influences at the Lawrence Scientific School: the Swiss naturalist Louis Agassiz (1807-73)[7], and the German-educated chemist Eben Norton Horsford. Deeply inspired, Caldwell set off for Europe soon after graduating.

[6] Caldwell, “American Chemist” 1892).

[7] Throughout his life Caldwell cherished his notes from Louis Agassiz's lectures. See "notes - Agassiz," 14/8/271-boxes 1&3, Caldwell Collection. Unfortunately I found little else pertaining to Harvard in Caldwell's papers. On the failure of the Lawrence Scientific School to realize the high hopes Horsford had set by it, see Rossiter, *Emergence*, pp. 74-88.

Caldwell first landed in England, where he made a courtesy visit to the Royal Agricultural College in Cirencester.[8] He then journeyed to the continent and enrolled at Göttingen in Hannover for the spring semester of 1855, where he intended to work with Friedrich Wöhler (1800-80). Wöhler was well known for his early work in organic chemistry, inclucing the synthesis of urea, as well as for work in inorganic chemistry, such as the discovery of aluminum. He attracted many American students, and there was a regular American colony at Göttingen.[9] Caldwell stayed one semester, then moved to Heidelberg in Baden for the winter semester of 1856-7, to study analytical chemistry with Robert Wilhelm Bunsen (1811-99) and physics with Gustav Robert Kirchoff (1824-87).[10] Bunsen was well known for his work in inorganic analysis and industrial chemistry, and Caldwell, like many students at German universities, took an eclectic approach toward doctoral education. Though the courses with Bunsen and Kirchoff included lectures, laboratory work was the heart of their teaching method. Caldwell's notebooks from both courses are heavily illustrated with diagrams of apparatus and experimental set-ups, and the notes from Bunsen's course in particular emphasize this empirical approach to chemistry. Returning to Göttingen, Caldwell studied physics with W. E. Weber (1804-91), mineralogy with Waltenshauser (not identified

[8] Caldwell associated briefly with Professor J. C. A. Voelcker (1822-84) at Cirencester, but it seems to have been a courtesy visit by a young American and not a serious term of study. I found no primary material pertaining to Caldwell's visit at Cirencester. Secondary references include:
A. a folder "Newspaper Clippings" includes an article on Caldwell's retirement, 14/8/271-box 2, Caldwell Collection.
B. George Chapman Caldwell - Biography Folder, Cornell Archives.
C. Emile M. Chamot and Fred H. Rhodes, "The Development of the Department of Chemistry and of the School of Chemical Engineering at Cornell," unpublished & undated, p. 1, 14/8/668, Cornell Archives. According to Chamot and Rhodes, Ezra Cornell (founder of the university), was very impressed by Caldwell's experience at Cirencester.

[9] H. S. van Klooster, "Friedrich Wöhler and his American pupils," *Journal of Chemical Education* 21(1944): 158-70.

[10] A few years later, c. 1860, Bunsen and Kirchoff became famous for their joint work in determining the spectral lines of elements.

further), and chemistry with Wöhler and Charles A. Gössmann (1827-1910).[11] Wöhler had semi-retired by this time, and Gössmann was responsible for teaching and supervising laboratory chemistry.[12]

Caldwell took the PhD from Göttingen in 1857. His thesis was titled "The Fatty Acids contained in the oil of the Arachis Hypogaea [peanut] and the Oleic Acid Series," and dedicated "To E. N. Horsford A. M., Professor of Chemistry in Harvard University as A Slight Token of High Respect, This Little Work is Most Respectfully Dedicated by His Former Pupil."[13] The work was performed in Wöhler's laboratory under Gössmann's direction. It was a routine but laborious piece of work for its day,[14] involving the application of well-established techniques of organic analysis to further characterize a fatty acid series discovered previously by Gössmann. Caldwell published four articles based upon his dissertation.[15]

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[11] Charles A. Gössmann (1827 - 1910) was Wöhler's assistant at Göttingen. He emigrated to the United States in 1857, and eventually found a permanent position at the Massachussetts Agricultural College in 1868. See C. A. Browne, "The History of Chemical Education in America between the years 1820 and 1870," *Journal Chemical Education*, 9: 696-728.

[12] While in Germany, Caldwell may also have visited Carl Remigius Fresenius's teaching laboratory and agricultural institute at Wiesbaden. Material on Caldwell's German coursework in the Caldwell Collection includes:
14/8/271-box 1 Prof. Bunsen's lectures, notes of Kirchoff's lectures on physics (two sets), notes on Heidelberg Botany lectures, drawings of Wöhler's apparatus used in his daily lectures
14/8/271-box 2 announcement book with Caldwell's grades from Göttingen (beginning 16 April 1855), schedule of classes from Heidelberg (winter 1856-7), pamphlet of the chemistry laboratories at Wiesbaden.
On Wöhler's career, see Robin Keen, "The Life and Work of Friedrich Wöhler," PhD dissertation, University of London, 1976.

[13] Caldwell dissertation, dated 1856, 14/8/271-box 3, Caldwell Collection.

[14] E. Pugh to S. W. Johnson, 15 November 1855, in Browne, "European Laboratory Experiences" (1930): 507.

[15] G. C. Caldwell, "Ueber das Paranussöl," *Liebig's Annalen* 98 (1856): 120-3.
_____, "Beitrage zur Kenntnis des Erdnussöls," *Liebig's Annalen* 10 (1857): 97-9.

Both Pugh and Caldwell disapproved of the ease with which Göttingen sometimes handed out PhDs to American students. Caldwell expressed strong disapproval when Gottingen granted a degree to a colleague (Clark, also an Agassiz student) for a thesis that was deemed unacceptable at Heidelberg.[16] Pugh disapproved in that American students usually avoided the PhD examination at Göttingen by leaving the university and then petitioning to be excused. Pugh and Caldwell did not know it, but PhDs were not always taken by German students in an honorable manner, either. For example, the young chemist Justus Liebig paid his *Doktorvater* 66 gold florins for the doctorate in lieu of actually writing and submitting a dissertation.[17]

Though Caldwell did not go on to do additional original research, his German education served well as a model in other ways for his professional life. During this era, chemistry was a German science. Just a generation earlier, German chemists such as Liebig and Wöhler had pioneered mass instruction in laboratory chemistry. Along with this came the expectation that students must publish the fruits of their labor. In professionalizing the practice of chemistry, the status of chemistry professors was elevated enough so that professors were paid relatively well. In large measure, the status of individual professors was rated by the number of students they could attract. To do this, German chemistry professors developed a strong sense of teaching duty. Bunsen and Wöhler instilled this sense of duty in Caldwell, and it called for extensive course preparation and long days spent in the laboratory with students.[18] Caldwell's close friend Evan Pugh described Wöhler's dedication:

> In Göttingen Professor Wöhler is a most assiduous teacher, takes a constant, deep interest in all his students, and devotes his entire time and interest to their

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_____, "On the Oleic Series of Fatty Acids," *American Academy Proceedings* 3 (1857): 349-53.

_____ and A. Gössmann, "Ueber einige Verwandlungs Products der Hypogäasäure," *Liebig's Annalen* 99 (1856): 305-14.

[16] G. C. Caldwell to W. H. Brewer, 2 December 1857, W. H. Brewer Collection, Yale Archives. I thank Professor Margaret Rossiter for providing me with copies of correspondence from the Brewer Collection.

[17] Pat Munday, "Social Climbing through Chemistry: Justus Liebig's rise from the *Niederer Mittelstand* to the *Bildungs bürgertum*," *Ambix* 37 (1990): 1-19.

[18] On Wöhler's and Bunsen's reputations for teaching, see J. R. Partington, *A History of Chemistry*, vol. 4, (NY: St. Martin's Press, 1964): 281-3, 320-1.

> promotion...[19]
> As a teacher he [Wöhler] is unsurpassed - his only fault (if any he has) is that he teaches too much.[20]

The German professors also set a high standard for chemical analysis; laboratory work was to be performed quickly but with extreme precision and careful attention to detail.[21]

In addition to this professorial ethic, there was one other major career influence on Caldwell from his days at Göttingen, and that was his close friendship with fellow student Evan Pugh. They took classes together, shared the same bookseller's account, and took long walks together.[22] After Caldwell left Göttingen, he again worked with Pugh for a short time under the direction of John Bennet Lawes (1814-1900) at Lawes' agricultural experiment station at Harpenden-Rothamstead near London, England. Unlike Pugh, he undertook no serious work at the Rothamstead experimental farm, and soon returned to America. He and Pugh kept up a correpondence that would bring them together again in the founding days of what would become The Pennsylvania State University. Pugh thought highly of Caldwell's abilities, but he worried about his prospects in the United States. He wrote S. W. Johnson at Yale:

> I sincerly hope Caldwell will get into a good position - none of my Göttingen American acquaintances merit it as much as he - none were as industrious - none

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[19] Browne, "European Laboratory Experiences," p. 503.

[20] Browne, "European Laboratory Experiences," p. 505.

[21] On the institutionalization of chemistry in the German states, see Bernard Gustin, "The Emergence of the German Chemical Profession, 1790-1867)," PhD dissertation, University Chicago, 1975.

[22] Two items labelled "Canto-Buch, Anno 1856," one by Caldwell and one by Pugh, with references to their friendship while at Göttingen, 14/8/271-box 2; folder "German Papers" includes the book account shared by Pugh and Caldwell; "vacation journal," 19-24 September 1855, mentions Caldwell's activities with the other American students at Göttingen, 14/8/411, Caldwell Collection. Also see Caldwell to Brewer, 6 August 1857, W. H. Brewer Collection, Yale Archives.

> more successful - and yet none as modest and unpretending as he. I'm afraid that his own modesty will be the means of his failing to be appreciated by those who have positons to give. If it lay on your way, Johnson, and you would lend him a hand you would reward merit and oblige your friend.[23]

A Young Chemist Starting Out

Shortly after his return to the United States, the young Dr. Caldwell thought himself fortunate to be hired as an assistant to Professor C. A. Joy at Columbia College (later, Columbia Univerity). His happiness with the position soon turned sour. Professor Joy turned out to be something of a disappointment: he undertook no chemical investigations of his own, he would not allow Caldwell access to his excellent laboratory, and when the trustees of the college would not approve payment for Caldwell, Joy reneged on his promise to pay Caldwell from his own pocket if necessary. In March of 1858, after seven months in New York City, Caldwell returned to the farm at Lunenburg with the vow "... [I] shall not again leave home for such a mean place as this at Columbia College."[24]

Caldwell worked on his father's farm and furthered his knowledge of botany through self-study. The market for chemistry professors in the United States was poor, but again Caldwell was fortunate. In 1859 he was appointed as professor of chemistry and physics at Antioch College, Ohio (1859-62). Caldwell lectured on botany in addition to chemistry and physics.[25] In 1861 he

[23] E. Pugh to S. W. Johnson, 8 November 1857, in Browne, "European Laboratory Experiences," p. 514. See also Williams, *Evan Pugh*, p. 45 on Pugh's efforts to find Caldwell a position with the University of Lewisburg in Pennsylvania (now Bucknell University).

[24] G. C. Caldwell to W. H. Brewer, 6 March 1858, W. H. Brewer Collection, Yale Archives.

[25] G. C. Caldwell to W. H. Brewer, six letters, 19 May 1858 - 20 June 1860, W. H. Brewer Collection, Yale Archives. Cf. "lectures & notes on botany - Antioch College," and "Antioch lectures on chemistry (in part), physics, botany," 14/8/271-box 1, Caldwell Collection.

wedded a local girl, Rebecca Wilmarth.[26] For reasons unknown, the couple left Antioch in 1862.[27] Later, while teaching at the Agricultural College of Pennsylvania, he longed for "the good old Antioch of days gone by." At the end of his service during the Civil War and while teaching at the Pennsylvania Farmer's College, Caldwell tried desperately to get rehired at Antioch. In vain, Rebecca made a trip there in 1865 to represent him to the trustees who were hiring new professors.[28]

Caldwell received an exemption from serving in the Union Army, but he did serve with a private relief organization, the United States Sanitary Commission. He served in an administrative capacity, overseeing the provisioning of medical supplies and blankets to wounded soldiers and regimental hospitals. The job included some hazardous duty, with travel to hospitalized prisoners in Richmond and Alexandria, under the threat of meeting hostile guerrilla forces. Caldwell also served in a more personal capacity. Among his papers from the U. S. Sanitary Commission are many letters from anxious wives, mothers and fathers who were seeking the where-abouts of their missing loved ones.[29]

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[26] Thomas Waterman Hewett, *The History of Cornell University, in the twenty-five years of its existence*. (Cornell University, undated): 694. Hewett implies Rebecca S. Wilmarth was from Ithaca, NY, and that she and Caldwell were married at Ithaca. Neither, I believe, is the case. Judging by the date of the marriage she is from Yellow Springs, OH, or perhaps Meadville, PA. Also, see the numerous mentions of her travel to Yellow Springs and to Meadville in G. C. Caldwell Diary, 14/8/271-box 2, Caldwell Collection.

[27] Caldwell mentions his deafness and a low salary as two reason for leaving Antioch, G. C. Caldwell to W. H. Brewer, 2 November 1860, W. H. Brewer Collection, Yale Archives. I do not know how severe Caldwell's deafness was. The only other mention of it is in a letter from a cousin. Despite Caldwell's letter of 1860, he remained at Antioch until sometime in 1862. Retirement notice in "Newspaper Clippings," 14/8/271-box 2, Caldwell Collection.

[28] G. C. Caldwell Diary, quotation 15 July 1864, Rebecca's trip to Antioch 25 June 1865, 14/8/271-box 2, Caldwell Collection.

[29] G. C. Caldwell Diary, September 1863 - June 1864, 14/8/271-box 2, and several sets of Civil War letters and U. S. Sanitary Commission papers from November 1862 to August 1864,

During the war Caldwell was granted several periods of leave in order to assist his friend Evan Pugh at the Agricultural College of Pennsylvania.[30] A few months after last assisting Pugh, Caldwell wrote in his diary:

> This morning came the terrible news of Pugh's death after a week's illness, and insensibility during most of that time... Poor Mrs. Pugh, one can hardly say poor Dr. Pugh; he would have worked himself to death in any case, and perhaps he can work now without so many earthly traumels to hinder him.[31]

Samuel W. Johnson was offered Pugh's post, but he declined it.[32] In July of 1864 Caldwell filled the vacancy and began a most hateful task. The job had come to him under the worst of circumstances, and he was also disappointed by the low academic standards and the backwater cultural isolation of his new home.[33] His days were busy ones: up at 6 AM, prepare lecture notes until 7:30, eat breakfast, get experiments ready, lecture at 10:00, recite Stöckhardt[34] at 11:00, "rest and behold wife" 11:45-12:45, instruct 16 - 18 students in qualitative and quantitative chemistry lab

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14/8/411, Caldwell Collection.

[30] Caldwell assisted Pugh in October - November 1863 after Pugh was injured in a horse and buggy wreck. See Margaret Tischan Riley, "Evan Pugh of Pennsylvania State University and the Morrill Land-Grant Act," *Pennsylvania History* 27 (1960): 356, and G. C. Caldwell Diary, 3 October - 11 November 1863, 14/8/271-box 2, Caldwell Collection. See also Williams, *Evan Pugh*, pp. 124-129 and 132-122.

[31] G. C. Caldwell Diary, 3 May 1864, 14/8/271-box 2, Caldwell Collection. Later (7 May 1864), Caldwell goes on to describe Pugh's demise. He raved, thought his wife was trying to murder him, was watched over by three strong men but hit one with a heavy chair and escaped for a time, and was delirious to the end.

[32] G. C. Caldwell Diary, 7 May 1864, 14/8/271-box 2 Caldwell Collection.

[33] Caldwell was particularly disappointed by the appointment of William Allen as President of the Agricultural College because he and other faculty believed Allen was taking the college in an unscientific direction. See Williams, *Evan Pugh*, pp. 168-170.

[34] Julius Adolphus Stöckhardt, *Chemical Field Lectures for Agriculturists*, trans. James E. Teschemacher (NY: Saxton, 1854).

1 - 3 PM, and after 4 PM "continue lab work or accounts, evenings for study." Caldwell tried desperately to get re-hired at Antioch, or to a new position at Massachussetts College or Allegheny College (Meadville, PA). Regarding his position he wrote "... and may I not again become so deeply involved in any young and struggling institution." As a way out, he considered buying a farm in western Pennsylvania or in Florida.[35] Throughout the ordeal George's father proved to be a staunch supporter and advisor. He offered to help George with whatever it might take to insure his success as a chemist, whether books, a private laboratory, or a trip to Europe. But in a letter he cautioned his son:

> I can't see, I must say, how it is you don't find of glad and happy content in your present conditions. Perhaps you find more than I imagine. But when you speak of disgust which you feel at things - of possibly being obliged to break your connection with the college on account of your dissatisfaction with it... [in order to avoid having your work published alongside inferior work in a Pennsylvania Agricultural College review of research] ... So far as your reputation is concerned or will be involved, it will be determined by your own productions and not by the general character of the work. And in regard to the labor which you fear, can you not with comparative ease do through former preparations what will be necessary for your classes and yet have time enough left for new work...[36]

[35] Part of George's discontent stemmed from Rebecca's frequent absences. It may have been that she cared for the cultural isolation of Bellefonte even less than did George. G. C. Caldwell Diary, 7 May 1864 - 26 July 1865, 14/8/271-box 2, Caldwell Collection.

[36] George Caldwell's father to George, 26 August 1867. This letter and many others from his father in 14/8/411, G. C. Caldwell Papers - Elsbree Collection, Cornell Archives.

George Caldwell had already taught chemistry at three American colleges, yet he felt compelled to rewrite his lectures to take into account the latest developments in the field. Like Pugh, he appeared to be working himself to death.

In 1867 it was beginning to look as if George Caldwell had settled in for a lifetime at the Agricultural College of Pennsylvania. He was vice president of the college, and he and Rebecca were living comfortably in the President's house. But Caldwell was still unhappy, and finally a new chance came. The scarce job situation of a few years earlier changed suddenly after 1866, as federal money from the Morrill Land-Grant Act began to lever its full effect.[37] In June of 1867 Caldwell refused an initial offer from Andrew White to join the faculty at the newly-formed Cornell University. But by October he had changed his mind and was busily preparing to join Cornell as professor of agricultural chemistry.[38]

[37] As a matter of good timing, Liebig published his greatly revised seventh edition of *Chemistry and Its Applications to Agriculture and Physiology* in 1862. This book helped restore the promise and popularity of chemistry as a way to augment agricultural production. See Mark R. Finlay, "The Rehabilitation of an Agricultural Chemist: Justus von Liebig and the Seventh Edition", *Ambix* 38(1991): 155-167.

[38] G. C. Caldwell Diary, 23 June 1867, 14/8/271-box 2, Caldwell Collection.

W. H. Brewer to G. C. Caldwell, 30 September 1867, G. C. Caldwell Papers - Elsbree Collection, 14/8/411, Cornell Archives.

G. C. Caldwell to W. H. Brewer, 21 June 1866 - 21 October 1867, W. H. Brewer Collection, Yale Archives. The letters to W. H. Brewer document Caldwell's application to Cornell University very well. Both Brewer and S. W. Johnson recommended Caldwell for the job.

Strangely, Caldwell never told his father about accepting the position. His father first read of it in a New York City newspaper article that announced the opening of Cornell. He was angry and confused, and fired off a letter to let George know exactly how he felt. (letter to G. C. Caldwell from his father, 22 December 1867, 14/8/411, G. C. Caldwell Papers - Elsbree Collection, Cornell Archives).

The Cornell Years[39]

a. settling in

From the start, Caldwell had high expectations of his place within the new university. He believed in the high aspirations that Ezra Cornell and Andrew White set for Cornell University. Before formally accepting a position, he sent President White an 8 page list of apparatus needed for the "Professor's Laboratory, Agricultural Department," a long list of required chemicals, a list of necessary books and journals that would cost $800, and a detailed list of architectural specifications labelled "Hints in regard to Laboratory." At least some of these wish lists had been solicited, seemingly with a promise of fulfillment, by White. White also inquired with Caldwell in regard to other faculty that might be hired away from the Agricultural College, but Caldwell had nothing good to say of any of his colleagues there. Caldwell taught his last semester in Pennsylvania in the spring of 1868 and moved to Ithaca, New York, in June.[40]

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[39] see Marlin G. Cline, *Agronomy at Cornell; Soils, Fields, Crops and Atmospheric Science 1868 - 1980*. (Ithaca: Department of Agronomy, Cornell University, 1982). Cline provides a nice overview of Caldwell's era. I thank Professor Emeritus Edward H. Smith of Cornell University for providing me with his copy of Cline.

[40] folder "G. C. Caldwell Papers," 14/8/271-box 3, Caldwell Collection.
"Hints in Regard to Laboratory" specifies:

A. for Dr. Caldwell
   1. working room, 300 - 400 sq. ft.
   2. balance room, 250 - 300 sq. ft.
   3. storeroom, 160 sq. ft.
   4. spectrograph closet, 5 - 6 sq. ft.
   5. furnace room, 160 sq. ft.

B. for students
   1. laboratory, 600 - 650 sq. ft. for 20 students
   2. balance room, 150 sq. ft.

C. for growing plants: a small conservatory, connected to a hot house

D. other specifications
   1. **no basement rooms!** [all emphasis is Caldwell's]

As Professor of Agricultural Chemistry and Dean of the College of Agriculture at Cornell University, Caldwell was immediately disappointed in two respects. At Pennsylvania, he had received a $1500/year salary with a house and garden. At Cornell, he received a salary of $1800/year with no perquisites.[41] Also, rather than the sectioned and well ventilated lab space he had requested, the chemistry laboratory was stuffed into a single large room in the dank basement of Morrill Hall, and was to be shared with James M. Crafts (Professor of Chemistry) and students.[42]

George and Rebecca lost no time in settling into their new home in Ithaca. They contracted for a house to be built, and on 25 December 1868 their first child was born (a son, Frank Cary Caldwell).[43] There were some problems with the house - according to George it was "full of leaks and creaks, crooked and leaning" - but after an out-of-court settlement with the builder, the faults were remedied and the house occupied.[44] George felt his Cornell salary was insufficient to provide for sea-side vacations and other amenities, and so he and Rebecca took in boarders. In 1874, they

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2. laboratories themselves should be sunny, for growing plants
3. work bench height, shelving requirements, etc.

As an overview of President White's efforts to establish the new university, see Carl L. Becker, *Cornell University: Founders and Founding* (Ithaca, New York: Cornell University Press, 1943).

[41] See "copy of letter sent to Mr. White accepting Professorship," 14/8/271-box 3, Caldwell Collection.

[42] Chamot & Rhodes, "Development," p. 38. The university library was on the ground floor (above the chemical laboratory), and, due to inadequate ventilation-exhaust, noxious fumes would occaisionally fill the library and drive everyone out.

[43] G. C. Caldwell Diary, 6 May 1871, 14/8/271-box 2, Caldwell Collection. After 1865, entries become few and far between summaries of Caldwell's life.

[44] letter from G. C. Caldwell to the building contractor, 3 September 1868; 8 page listing "flaws of the home;" a folder "receipts & bills, 1868 - 1869," includes receipts from work done on the Caldwell's house by P. A. Bouton, all in 14/8/411, G. C. Caldwell Papers - Elsbree Collection, Cornell Archives.

boarded 8 people, including George's father, and Professor and Mrs. Breneman. A daughter, Grace Wilmarth Caldwell, had been born to them 3 July 1870. This certainly made for a full house, and to assist Mrs. Caldwell wages were paid to seven domestic helpers in 1874. All of this may have taxed her patience, for in George's last diary entry (9 May 1875) he spoke of his wife's unhappiness. She was sleeping in a room with the children, whereas George, begrudgingly, was sleeping alone in a small room off the hall.[45] Several years later, the Caldwells rented out their first house, moved into a house on campus, and enjoyed summers at a small lake house.[46] At last the Caldwells had achieved the level of lifestyle they felt befitted them.

b. academics

George Caldwell taught for 35 years at Cornell (1868-1904). Over this period of time, the institution of chemistry underwent major changes in America and at Cornell University . Caldwell played an active role in both. He was deeply serious about teaching and held the highest expectations for his students' work, whether they majored in agriculture, chemistry, engineering, or liberal arts. In the early days of Cornell University, it took a devoted professor to overcome the many trials.[47] The first chemical laboratory in the basement of Morrill Hall had no plumbing; water was carried in by the pail, and wastes were collected and carried away in glass jars. After a

[45] G. C. Caldwell Diary, 9 May 1875; "Account Book, 1867 - 1879," pp. 85, 109, 144-6, 164-5, both items in 14/8/271-box 2, Caldwell Collection.

[46] "Cash Book, 1880 - 1890," pp. 60, 64, 151, 14/8/271-box 2, Caldwell Collection. The Caldwell's proved quite adept at managing real estate. In 1891, in addition to the afore-mentioned properties, they owned a house on Lake Street in Ithaca and two cottages built adjacent to their own summer lake home. see "Account Book, 1890 - ," 14/8/411-box 2, Caldwell Collection.

[47] Of the many professors of chemistry hired in the early days of Cornell University, only G. C. Caldwell remained for a lifetime. His first colleague, J. M. Crafts, e. g., taught for one year, left on a leave of absence to study in Germany, and never returned to Cornell. Crafts later became president of the Massachussetts Institute of Technology. See Chamot & Rhodes, "Development," p. 6.

few years of this, a large “temporary” wooden structure was built and used as the laboratory for more than ten years.[48] Mischevious undergraduates being always and everywhere the same, "Professor Caldwell was applying for `a good three-tumbler lock on the laboratory door,' since he feared the original lock could be too easily picked by students who seemed overanxious to get hold of malodorous chemicals."[49] Prior to 1872, when Stephen Moulton Babcock (1843-1931) became Caldwell's first graduate student and teaching assistant,[50] Caldwell gave lectures, laboratory sessions and recitations without aid. Until 1875 and perhaps later, Caldwell kept the chemical laboratory accounts and paid sundry expenses (reagents, clothes hooks for the laboratory, glue to repair chairs) out of his own pocket.[51] Caldwell also served as a sort of goodwill representative for the new university, receiving and answering inquiries from prospective students concerning career choice, employment prospects in chemistry, and the costs of a Cornell education. One letter is typical of the many:

> Plattsmouth, Nebraska November 26th, 1869
>
> Dear Sir
> will you please to the following questions which I address to you, as fully and plainly as you can? I am nineteen years of age with a very limited education. I think I could pass a pretty fair examination in geography. In Grammar to to [sic] etymology and in Arithmatic [sic], through decimal fractions. Algebra I have just commenced. I am a farmer by birth and have spent the most of my life on a farm except carrying the mail a year, and clerking in a retail dry goods & grocery store one month and a half. Now I am very anxious to take the four year course in the

[48] Hewett, *History*, pp. 584-5.

[49] Philip Dorf, *The Builder: A Biography of Ezra Cornell* (NY: MacMillan, 1952): 358.

[50] *Cornell University Register 1872 - 73*. (Ithaca, NY: Cornell University, 1873): 87. Babcock, as a professor at Wisconsin, later became famous for the "Babcock test," a means for determining the percent butterfat in milk.

[51] Expenses were periodically reimbursed by the university. "Account Book, 1867 - 1879," 14/8/271-box 2, Caldwell Collection.

> agricultural department of the Cornell University, but have lately heard that the applications for admission are so numerous that the present capacity of the University can not accomodate them. Now I have not the means of taking the course at present even if I could pass an examination - and unless I should be very fortunate it will be several years before I can get the means..."[52] [several letters of reference included]

The university catalog described three options within the Department of Agriculture. The regular four year course required two years of general arts and sciences, including a full year of general chemistry, before going on to specialized agricultural courses. Three year and two year abridged courses were also offered, with progressive deletions in the liberal arts and science requirements and with reduced admission requirements. The varied options increased Professor Caldwell's burden, with students at vastly different levels all enrolled in the same Agricultural Chemistry class.[53] The class was a sort of one room schoolhouse for chemistry.

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[52] Quotation from one of more than a dozen such letters, "correspondence 1868 - 1869,) 14/8/411, G. C. Caldwell Papers - Elsbree Collection, Cornell Archives.

There is also a letter from Theodore B. Comstock of Cleveland, Ohio, dated 12 August 1869, asking for advice on his career plans. T. B. Comstock had been a student of Caldwell's at Pennsylvania (see "Account Book - 1867 - 1879," 14/8/271-box 2, Caldwell Collection). He must have been a good student:

> "Valuable assistance in testing this and other methods of analysis has been received from Mr. T. B. Comstock, while a student in my laboratory." (from the introduction to an elementary text edited and translated by Caldwell)

T. B. Comstock graduated from Cornell in 1870, B.S. - Natural Science (*Cornell University Register 1869 - 70*, p. 114). He returned as an assistant professor of geology in 1875 (*Cornell University Register 1875 - 76*).

[53] Cf. "Catalog of the Officers and Students of the Cornell University" (Ithaca NY: Journal Steam Power Press Print, 1869): 34-48. This catalog is bound with the *Cornell University Register 1869 - 69* in the Cornell Archives.

In 1874, I. P. Roberts succeeded Caldwell as Dean of the Agricultural Department.[54] The following year Caldwell was named Professor of Analytical Chemistry while retaining the Professorship in Agricultural Chemistry, with his teaching load increased by the addition of lecture courses in chemical analysis, organic chemistry and, later, quantitative methods and a readings course. But at last he had assistants, and they taught the laboratory classes in Chemical Practice which c. 1885 was split into Qualitative and Quantitative Analysis. Beginning in the 1880's, special laboratory courses were developed for engineering students. Caldwell's assistants taught the laboratory classes, but he wrote the manuals and exam questions. In 1891 Caldwell was named Professor of General Chemistry. Typical of his teaching load during this period was the academic year of 1897-8, when he taught and supervised ten sections (seven preparations):

> Advanced Quantitative Analysis - supervised by Caldwell, taught with associate professors, instructors, assistants
> General Inorganic Chemistry
> Elementary Agricultural Chemistry
> General Agricultural Chemistry
> General Chemical Readings
> History of Chemistry
> Chemistry of Food & Beverages
> Physiological Chemistry

The precise number of students enrolled in each of these courses is unknown. There were 84 students enrolled in the Agricultural College that year, and about twelve enrolled as chemistry majors in the College of Arts and Sciences.[55] Though he taught a full schedule, each of Caldwell's classes must have been fairly small, probably with no more than 25 students in even the largest.

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[54] Roberts proved to be an able and practical manager of the Agriultural School, from 1874 - 1903. I thank Dr. M. W. Rossiter for bringing his autobiography to my attention:
Isaac Phillips Roberts, *Autobiography of a Farm Boy* (Albany: J. B. Lyon, 1916).

[55] For data on courses, assistants, and numbers of students, see the *Cornell University Register*, published each academic year.

c. textbooks

George Caldwell's publications generally took one of two forms. He wrote a number of brief articles concerning his work as an agricutural chemist, and a number of textbooks to instruct students in chemical analysis. He wrote these because he was dissatisfied with the elementary texts available to his students:

> The work in chemical analysis usually taken in this University [Cornell] calls for as brief and precise a course in qualitative analysis as will fit the student for elementary quantitative work. No one of the numerous small treatises on this subject issued in the past few years satisfactorily meets this want, while the methods laid down for the separation and detection of substances are often unsuccessfull in the hands of the majority of beginners in the study."[56]

In Caldwell's first year at Cornell (1868), both he and Professor Crafts were working on elementary laboratory textbooks, and probably each used his own draft for class instruction.[57] The following year Caldwell's text, *Agricultural Qualitative and Quantitative Chemical Analysis*, was in publication and required for laboratory.[58] This became a popular text and achieved a widespread reputation:

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[56] G. C. Caldwell and S. M. Babcock, *A Manual of Qualitative Chemical Analysis* (Ithaca, NY: Cornell University Press, 1875): introduction.

[57] James Mason Crafts, *A short course in qualitative analysis with the new notation* (NY: J. Wiley, 1869). This text went through at least three editions; the 3rd edition was used by Caldwell, in conjunction with his own text co-authored with Babcock, for laboratory instruction in 1880 ("Lectures on Agricultural Chemistry," 14/8/271-box 1, Caldwell Collection).

George C. Caldwell, ed. and trans., *Agricultural Qualitative and Quantitative Chemical Analysis, after E. Wolff, Fresenius, Krocker, et al.* (NY: Orange Judd & Co., 1869).

[58] *Cornell University Register 1869 - 70*, p. 92.

> [This book] was the first work on that subject in the English language, and it contributed greatly to arouse in this country an active interest in the important field that had so brilliantly been opened by Liebig in Germany.[59]

In 1875 Caldwell and a loyal former student who had followed him from Pennsylvania, Abram A. Breneman, published *A Manual of Introductory Chemical Practice*.[60] Caldwell and a former graduate student, Stephen Moulton Babcock, co-authored the sequel, *A Manual of Qualitative Chemical Analysis*, to this text in 1882.[61] Caldwell published a polished and final volume in his quest for the perfect lab manual in 1890, *Elements of Qualitative and Quantitative*

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[59] L. M. Dennis, "George Chapman Caldwell" [obituary], *Proceedings of the American Chemical Society* (1909): 7-8. I thank Professor Emeritus W. T. Miller of Cornell University for bringing this obituary to my attention. Cf. C. A. Browne, *A Half-Century of Chemistry in America, 1876-1926* (Philadelphia: ACS, 1936): 184.

[60] George C. Caldwell and Abram. A. Breneman, *A Manual of Introductory Chemical Practice* (Ithaca, NY: Cornell University Press, 1875). Breneman, originally a student of Pugh's, finished his B.S. under Caldwell at Pennsylvania in 1866 (Riley, "Evan Pugh,"p. 353). He then assisted Caldwell there until 1868 ("Account Book, 1867 - 1879," 14/8/271-box 2, Caldwell Collection). He first assisted Caldwell at Cornell in 1874 (*Cornell University Register 1874 - 75*, p. 15), was named assistant professor of applied chemistry 1875-6 and assistant professor of analytical chemistry 1877-8. In 1880 he was appointed to study the sanitary systems and water supply of Ithaca. He was critical of both, fell into local disfavor, and was forced to resign (ostensible on religious grounds) in 1882 (Chamot & Rhodes, "Development," pp. 9-10). Breneman returned to the Agricultural College of Pennsylvania to become a professor of chemistry there (Riley, "Evan Pugh," p. 353).

On Breneman, see Pat Munday, “A. A. Breneman (1847-1928”), biographical entry in Wyndham D. Miles, ed., *American Chemists* (Guildford Conn: Gould Books, 1994): vol. 2, pp. 30-31.

[61] G. C. Caldwell and S. M. Babcock, *A Manual of Qualitative Chemical Analysis.* (Ithaca, NY: Finch & Apgar, 1882). Subsequent editions 1885, 1889. Babcock was listed as a graduate student (chemistry) in the *Cornell University Register* from 1872 to 1875, and as a special member of the faculty from 1875 to 1877. I do not know what he did as Caldwell's graduate student. For Babcock's subsequent career, see Aaron J. Ihde, "Stephen Moulton Babcock - Benevolent Skeptic," in Duane H. D. Roller, ed., *Perspectives in the History of Science and Technology* (Norman: University of Oklahoma Press, 1971): 271-82.

Chemical Analysis.[62] Although elementary, all of his textbooks stressed the thoroughness and precision, traits central to the German-derived foundations of Caldwell's philosophy of laboratory work:

> **Carefulness in Analysis.** You cannot be too careful in making a quantitative analysis. The moment one begins to be a little careless, knowingly, he is on the way downwards. He begins to lose confidence in his analysis, and hence loses interest, and this begets further carelessness, and a poor result: hence discouragement on the part of the young analyst.
>
> When making an evaporation, filtering out a precipitate, washing it, transferring a quantitative from one dish to another, the proper use of reagents, etc. - there are many chances for error; some of these cannot be guarded against therefore it is all the more important to pay attention to those sources of error that can be avoided. When there is doubt felt, although perhaps in the smallest degree, of the expediency of doing a thing in such and such a manner or of manipulating in this or that way , because of a certain chance of the process working in another way than the right one, don't give this chance, though it may be but one in a hundred, the opportunity of spoiling your analysis, if another way can be found, which is free from any such defect, so far as you can judge. Don't say "I'll risk it" but take the surer way, though it may be a roundabout road, whereas the other was shorter, and would carry you straight to the desired object - provided a certain thing, or certain misfortune didn't happen to befall you. Patience may be required to travel the longer road: but patience thus acquired will be of use in other departments of life. Be careful in the extreme, rather than careless in the least.[63]

At this time, the chemical laboratory was open daily 9 AM - 5 PM. Laboratory work, whether on known chemicals for practice or on unknowns for examination, was not acceptable if in error. All

[62] G. C. Caldwell, *Elements of Qualitative and Quantitative Chemical Analysis* (Ithaca, NY: Andrus & Church, 1890).
2nd edition - (Philadelphia: P. Blakiston, Son & Co., 1892).
In the preface, Caldwell describes this text as an extensively reworked combination of Caldwell & Babcock, *A Manual* (3rd ed., 1889), and Caldwell, *Notes on Chemical Analysis* (I was unable to find a date for this).

[63] Lecture notes for a Qualitative Lab course, 25 October 1886, 14/8/583, Caldwell Collection. In 1868-69, chemistry majors were required to spend six hours each day in laboratory. (Chamot & Rhodes, "Development," p. 6)

work was to be repeated until correct![64] Any good instructor knows that a student's first experiences in a new field must be programmed for success. Caldwell's laboratory manuals helped to lead students step-by-step to the "right" results, thus boosting the students' confidence and helping them achieve their professor's high expectations.

d. professional service

Caldwell's other publications were oriented around the role he played as an agricultural chemist and as a member of the professional chemical community. These publications are of minor scientific interest, but they are of major interest for understanding how science could be applied to serve agriculture in the late nineteenth century. New York State farmers were eager to receive the benefits promised by science and they lost no time in making demands of the new college of agriculture. The American Dairymen's Association sent the trustees of Cornell University a report of their national convention of 1869, with a request that the university investigate abortions in cows and perform chemical analyses of milk and rennet. The requests were forwarded to Caldwell. Caldwell was invited to address the 1870 national convention in Utica, New York, after S. W. Johnson declined. Caldwell read an address to the 1871 national convention (also at Utica), "Methods of Cheese-Making in Europe." Caldwell became a favorite of the group, returning to Utica in 1872 to read "The Practical Value of Chemical Analyses of the Dairymen's Raw Materials and of the Products of His Manufacture." During this time, Caldwell performed a number of analyses for the association, including one on cheese suspected of white-lead contamination after having been made in a freshly painted tub.[65]

[64] See "Introduction, lecture notes for a Qualitative Lab course," 25 October 1886, 14/8/583, Caldwell Collection.

[65] See folder "American Dairymen's Association Letter & Resolutions," 14/8/271-box 3, Caldwell Collection.
Also, a folder "Notes on Milk Preservatives," 14/8/411, G. C. Caldwell Papers - Elsbree

The contaminant analysis of cheese is an example of one of the more successful applications of chemistry in the late 19th-century. Well established analytical procedures could be used to determine the true composition of fertilizers, the amount of fat in milk, the adulteration of butter with margarine, and the safety of drinking water. George Caldwell was by training and temperament preeminently an analytical chemist, and he was eager to demonstrate the utility of his science. In the 1880's he was employed by the New York State Board of Health (Department of Hygiene) to test for water quality and dairy product purity throughout the state.[66] Furthermore, he taught many elements of what would come to be known as sanitary chemistry in his lecture courses.[67] Unfortunately, some other agricultural applications of chemistry proved too complex for straightforward analytical technique alone to overpower.

Inspired by Liebig, agricultural chemists of Caldwell's era hoped to explain animal and plant physiology using a model developed from simple analytical chemistry.[68] Caldwell's notes on published work by Liebig's student, the physiological chemist Julius Alexander Lehmann (1825-94), stated simply: "an animal is an apparatus of combustion; a vegetable is an apparatus of reduction."[69] Ash analysis could determine what plants were composed of and therefore what they

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Collection," includes a commercial advertisement for "Liquid Extract of Rennet for Pure Flavored Cheese" sold by Whitman & Burrell, "Developed & Prepared by Professor Caldwell and Professor Arnold of Cornell University," undated.
Perhaps Caldwell tried to capitalize on his chemical knowledge, or, Whitman & Burrell hoped to capitalize on Caldwell's reputation. I have found no documents to establish any formal connection between these parties.

[66] "Cash Book," pp. 150, 168-9, 14/8/271-box 2, Caldwell Collection.

[67] Chamot & Rhodes, "Development," p. 58. Chamot & Rhodes also tell of Caldwell's routine use of the microscope for water quality investigations. Also, see the various sets of course notes, especially Agricultural Chemistry, in the Caldwell Collection and in "Chemistry Department - exams & lectures, notes - 1880-92, 14/8/49, Cornell Archives.

[68] Pat Munday, "Liebig's Metamorphosis: from organic chemistry to plant physiology," *Ambix* 38 (1991): 135-154.

[69] "Chemical Record," p. 156, 14/8/271-box 1, Caldwell Collection.

required for growth; soil analysis could reveal what was missing; therefore soil deficiencies could be remedied by applying proper amounts of the correct magic fairy dust.[70] As an example of this program, from 1874 to 1879 Caldwell ran a series of field trials on 33 small plots of maize in order to compare the effects of various fertilizers. Weights of fodder and corn production on each plot were recorded.[71] These trials produced no conclusive results, but they were typical of the high hopes that chemists held for the simple solution of practical agricultural problems. Caldwell himself cautioned his colleagues against expecting too much of mere chemical analysis. He was well trained in botany and held a continuing interest in it, and it might have been expected that he would adopt a more biological and physiological process-oriented (vs. input-output) approach to field experiments. Too, he kept abreast of the latest developments in related fields such as microbial theory.[72] Yet simple chemical analysis and the input-output method remained the model for agricultural experimentation for Caldwell, his colleagues, and his farming audience. His report on the 1874-9 fertilizer trials was reprinted as late as 1887,[73] and in 1891 he participated in a

[70] This reductive syllogism stemmed directly form Liebig's work of the 1840s. See Munday, "Liebig's Metamorphosis".

[71] Folder "Feed Analysis & Reports on Corn Experiments," 14/8/411, G. C. Caldwell Papers - Elsbree Collection, Cornell Archives.

[72] See "Lectures: The first garden - Useful hints concerning its management (pp. 299-302), The flower garden and conservatory and lawn - Useful hints concerning their management (pp. 319-21);" "Lectures on Agricutural Chemistry - 1880," where notes about yeast and bacteria are pasted over original material; "Notes of Lectures - Heidelberg Botany" (two sets), all in 14/8/271-box 1, Caldwell Collection.

Also see G. C. Caldwell, "The More Notable Events in the Progress in Agricultural Chemistry, Since 1870," *American Chemical Society Journal* 14 (1892): 83-111.

Caldwell may never have accepted the Darwinian hypothesis of evolution. In his papers are several sets of undated notes on the "Development Hypothesis," arguing evolution vs. the expression of God's will. I do not know if these ideas were held by Caldwell, or if they are merely notes from Agassiz' lectures.

[73] G. C. Caldwell, "Experiments with Various Fertilizers on Indian Corn," pp. 29-35, in Cornell University, *Studies in Practical Agriculture* (Ithaca: 1887).

symposium on the same topic.[74] One of his last graduate students, Cyril G. Hopkins, wrote a dissertation on "The Chemistry of the Corn Kernel" in 1898.[75] Such labors were not entirely useless: when corn breeding programs began after 1900, reliable analyses like those by Hopkins were necessary for determining the relative gains (and losses) in essential nutrients.[76]

If a chemical basis could be established for corn fertilizer, the same could be done for cattle fodder. As Director of the Cornell University Experiment Station (1879-1885), Caldwell designed and reported on a number of cattle feeding experiments, all based on input-output analyses. Most of these experiments consisted of attempts to correlate the constitution of the fodder with physiological effects in the cow (e.g., weight gain or milk quality).[77] His experience in this line led

[74] G. C. Caldwell, "A symposium onfield experiments with maize and suggestions for further experimentation," *American Society of Agricutural Science Proceedings* (1891-2): 30-8.

[75] C. G. Hopkins, "The Chemistry of the Corn Kernel," unpublished Ph. D. thesis, Cornell University, 1898. Published by the University of Illinois Agricultural Experiment Station, Bulletin No. 53, 1898.

[76] Hopkins continued Caldwell's analytical chemical approach to agricultural problems as a professor at the University of Illinois. He also invented the "ear-to-row" method of selection and improvement. For a splendid portrayel of Hopkins' stubborn personality and set scientific style, as well as his real accomplishments, see Deborah Fitzgerald, *The Business of Breeding: Hybrid Corn in Illinois, 1890-1940* (Ithaca, NY: Cornell University Press, 1990).

[77] See "letters regarding feed stuff analysis," 1888, 14/8/583, Caldwell Collection; and G. C. Caldwell, "A Comparison of the Productive Effect of the Same Ration with Different Breeds of Cows," pp. 16-18; "The Gain of Steers on a Fattening Ration," pp. 18-20; "The Effect of a Maintenance Ration," pp. 20-3; "The Influence of the Ration on the Composition of Milk," pp. 35-42; " Malt Sprouts Compared with Grain, and Ensilage Compared with Dry Feed for Milch Cows," pp. 107-9, all in Cornell University, *Studies* (1887).

Though beyond the scope of this paper, the inspiration that German and British agricultural experimenmt stations provided for the American model and the global ascendance of Amerian agricultural stations over their German and British counterparts is an important topic. See Mark Finlay, *Science, practice and politics: German agricultural experiment stations in the nineteenth century*, PhD disseration, Iowa State University, 1992.

to his active involvement with the Association of Official Agricultural Chemists (AOAC), with which he was chairman of the committee for the analysis of cattle foods (1886-90). Caldwell saw the goal of the AOAC as "the establishment of uniformity in methods of technical chemical analysis."[78] Caldwell was very active in serving this goal, by criticizing and correcting the analytical methods of his colleagues.[79] They respected his ability and in 1891 he was elected president of the AOAC.

Caldwell also became active with the Chemical Section of the American Association for the Advancement of Science (AAAS). He first became a member of the American Chemical Society (ACS) in 1890, and was elected to the Advisory Council of the ACS in 1891. At the national ACS meeting of that year, the ACS invited the Chemical Section of the AAAS to merge in order to form "a general organization of chemists in America."[80] The merger was effected, and in 1892 George Caldwell was elected ACS president.[81]

In his farewell address as ACS president, Caldwell reflected on the state of chemistry in America:

> Why is it , with so many of these institutins as we have, making claim to this high rank in our system of instruction, that we fall so far short of contributing our

[78] G. C. Caldwell, "Address of Mr. G. C. Caldwell, President," USDA - Division of Chemistry Bulletin no. 31, *Proceedings of the Eigth Annual Convention of the Association of Official Agricultural Chemists* (1891), p. 7.

[79] see the active discussions in:
G. C. Caldwell, "Report of the Committee on the analysis of cattle foods," USDA - Div. of Chemistry Bull. no. 16, *Proceedings of the Fourth Annual Convention of the AOAC* (1887): 8-12.
_____, "Report on the Analysis of Cattle Foods," USDA - Div. Of Chemistry Bull. no. 24, *Proceedings of the Sixth Annual Convention of the AOAC* (1890): 15-72.
_____, "Report on the Analysis of Cattle Foods," USDA - Div. of Chemistry Bull. no. 28, *Proceedings of the Seventh Annual Convention of the AOAC* (1890): 79-90.

[80] *American Chemical Society Journal*, 13(1891): 1,3, appendix p. 1.

[81] *American Chemical Society Journal*, 14(1892): 3.

> full share of the world's acquistition of new knowledge, year by year? The first and perhaps most important reason is that those upon whom this work devolves, and who would be glad to do it, have no time for it. Their work of instruction, often comprising many branches of science, uses up all their energy. This unfortunate condition of affairs is chargeable, to a large extent, to the multiplicity of colleges with endowments inadequate for the performance of the whole work of a college. It may be fairly said that no institution of learning is fully worthy of being called a university, or a college of high rank, that does not provide teachers enough, so that each one has spare time for investigation. There is room for improvement in this respect, even in some of our largest universities. It is not always practicable for an outsider, such as the average trustee is, to get so thorough an acquaintance with the inner workings of the seveal departments, as to understand how most of a teacher's time may be consumed in the management of the petty details of a laboratory full of students, provided that he does his duty there.[82]

Caldwell's activities as professor, as professional society scientist, and as publishing scholar peaked in the year 1892. Only as a teaching professor was he active after this time. The reasons for this are not clear. Perhaps he realized that both chemistry and agricultural science were entering into a new realm into which he was not prepared to follow.[83] Perhaps he felt that it was time to

[82] Caldwell, "American Chemist" (1892) at p. 347.

[83] I think, too, Caldwell felt his life's work had been accomplished. Indeed, not only were the institutions of chemistry and the agricultural sciences on secure ground, but so was the profession of science as an academic pursuit. On the emergence of graduate education and research in America, see Robert E. Kohler, "The Ph. D. Machine," *ISIS* 81(1990): 638-62. Cf. John

relax: his father, always George's confidant and inspiration, passed away in 1889;[84] his son, Frank Cary Caldwell, was now a successful researcher (electrical engineering) in his own right.

Caldwell retired from Cornell University in 1903. He delivered his general chemistry lectures for another year, as professor emeritus. He died in 1907 having lived to see American agricultural science prosper. He left his mark on the societies and institutions that he was associated with, but most of all on his students:

> . . . he was an excellent teacher, with the ability to arouse and maintain the interest and enthusiasm of his students. He is reputed to have been a tireless worker; it is said that he was the first to arrive at the laboratory and usually the last to leave it in the evening, and that he often returned to work at night . . .
>
> The traditions of hard work and of precise and careful measurement were heritages from Dr. Caldwell. So also, but less fortunately, was the extreme emphasis placed on analytical chemistry.[85]

Conclusion

When we judge the contributions of 19th century chemists, we can look to Justus von Liebig as a sort of benchmark. Liebig's contributions included developing important new methods for

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W. Servos, *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America* (Princeton, NJ: Princeton University Press, 1990).

[84] "Cash Book, 1880-90," 14/8/271-box 2, Caldwell Collection.

[85] Chamot & Rhodes, "Development," pp. 62-3.

analysis such as the *Kaliapparat*, opening fundamental new research pathways such as plant physiology, establishing new instructional methods for undergraduate and graduate instruction, and using a professional journal to build a vast international network.[86] Liebig, however, worked in a European culture where science was established as an academic and professional pursuit.

George Caldwell, on the other hand, worked in an America where science was just becoming established—largely thanks to the new land grant university systen. As an agricultural chemist Caldwell seldom saw beyond the limits of applied analytical chemistry to the greater possibilities of agricultural science. Yet he furthered agricultural science in two important ways. First and foremost, he was a fine teacher. Analytical chemistry is a craft born of long hours in the laboratory and subtle technique. Students like C. G. Hopkins were able to expand Caldwell's craft to the sure analysis of ever more complex biological molecules. Combined with the emergence of new sciences like structural chemistry and genetics, real gains were made in practical agriculture. Some of these gains are still understood only in empirical terms (e.g., the genetic basis of hybrid vigour), others are of questionable benefit (e.g., the rapid weight gain of steroid-fed cattle). The agricultural sciences have proved their ability to provide answers to questions like these. What now lies before us is the need to decide which questions are worth asking, which answers worth employing.

Caldwell also helped to forge the professional role and the institutional setting within which the agricultural sciences could advance. Initially, agricultural science promised a rational basis that would insure the farmer's prosperity. At best, farmers have broken even on the deal: American farmers no longer worry about the mysteries of "worn-out soil" or balanced cattle rations, but they are not getting rich from corn and milk surpluses either. The problems inherent in contemporary

[86] On Liebig's overall achievements, see: Pat Munday, "Sturm und Dung: Justus von Liebig (1803-1873) and the chemistry of agriculture", Cornell University PhD dissertation, 1990; and William H. Brock, *Justus von Liebig: the chemical gatekeeper* (Cambridge University Press, 2002).

agriculture do not, strictly speaking, stem from its dependence upon science and technology. The question remains, have agricultural researchers at the land grant colleges asked the right questions, promoted the right answers?

Appendix I: Chronological Bibliography of Caldwell's Work

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Appendix II: Positions Held by Caldwell

October 1857-March 1858: Assistant chemist to Professor Joy at Columbia College, $600 (probably never paid).

June(?) 1859- (?) 1862: Professor of chemistry and physics, Antioch College, salary unknown.

November(?) 1862-July 1864: United States Sanitary Commission, salary raised to $100/mo. in April 1864 (initial salary unknown).

July 1864-May 1868: Pennsylavania Agricultural College, $1500/yr., house and garden included after September 1866.

June 1868-1904: Cornell University

academic

1868-91: professor of agricultural chemistry

1875-91: professor of analytical chemistry

1891-1902: professor of general chemistry

1902-04: professor emeritus

administrative

1868-74: dean of agricultural college

1872-86: faculty secretary

1879-86: director of agricultural experiment station

salary

1868-71: $1800/yr.

1872-79: 2000

1880: 2250

1881-83: 3000

1884-89: 3667

1890-(?): 4000

1881-90 (possibly longer): NY State Board of Health

salary

1881-85: $200/yr.

1886-89: (?)

1890-(?): 2000

1886-91 (possibly longer): member, Association of Official Agricultural Chemists (AOAC)

1886-90: chairman, committee for the analysis of cattle foods

1891: president, AOAC

1890-190(?): member, American Chemical Society (ACS)

1892: president, ACS

Appendix III: A note regarding Caldwell's "Chemical Records"

Caldwell filled volumes with extensive indexes of articles and books of interest to him. The earliest of these he entitled:

> "Chemical Record of Geo. C. Caldwell
> Commenced Sept. 1st 1853.
> Thoughts on Chemistry and Miscelleneous Extracts from Chemical Writings."

This record includes a dictionary listing of reactions, notes from *Jahresbericht* 1853-5, and short summaries by Caldwell of the chemical texts of Lehman, Boussingault, and Dumas. A later index "Began June 1st 1865 to Index Renum[?] with reference to farming, myself." This is written at the time that he was considerin giving up the academic life for farming. Later, after he had left Pennsylvania for Cornell, the nature of the indexes changed somewhat:

> "Beginning June 1st 1868 I [?] or not to index everything chemical but only these articles which from their present or prospective intent seem worth the trouble of indexing - and this will be the case even particularly with periodicals or books which are themselves provided with a copious alphabetical index."

This rigorous indexing continued to the end of Caldwell's career. Why did he pursue this task of trying to keep up with new developments in all of the subfields of chemistry - physiological, industrial, theoretical, ... ? When Caldwell studied in Germany, many eminent chemists were still versed in all major fields of chemistry. New developments and the volume of literature rapidly made this impossible after 1860, but Caldwell continued to try. Over the years, the indexes did

favor agricultural chemistry over other fields, but only slightly. Also, it is noteworthy to point out that "agriculture" replaced the topic "farming" in 1874. These changes coincide with Caldwell's increased involvement with agricultural interests and professional agricultural chemical work. More importantly, I think Caldwell used these record books to keep his lecture material current. Also, when necessary, he could have reviewed the record books in order to develop new courses or to put together extra-curricular lectures.

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