65. J. A. Le Bel, "Les relations du pouvoir rotatoire avec la structure moléculaire", *Revue scientifique*, **1891**, *48*, 609-617. Aromatic compounds are discussed on p. 615. This paper, very relevant for understanding the distinction Le Bel meant to stress between his own theory and the structural theory of van't Hoff, again gives evidence for those aspects of Le Bel's ideas mentioned in footnote 35, still persisting in 1891.

66. "Le cinquantenaire de la théorie du carbone asymétrique", *Bull. Soc. Chim.* (Paris), **1925**, *37*, 341-356.

67. *Ibid.*, pp. 353-4. The relevant part of the original text reads: "... les deux corps ortho-1.2 et 1.6 sont identiques tandis que d'après van't Hoff le corps 1.2 oú il y a double liaison entre les carbones doit différer du corps 1.6 oú il y a la liaison simple." (I am very grateful to Prof. J. Michael McBride for pointing me out the logical incongruence originating from the misprint: the last 1.6 must read 1.2).

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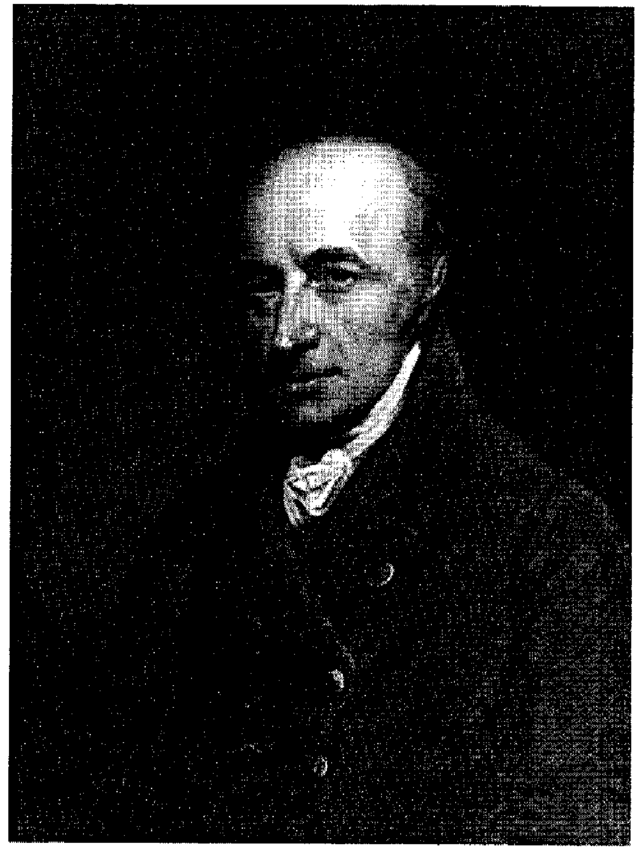
SOME EARLY CHEMICAL SLIDE RULES

William D. Williams, Harding University

An article by George Bodner in the Winter 1990 issue of the *Bulletin* described a rare chemical slide rule designed by Lewis C. Beck and Joseph Henry - their little-known "Improved Scale of Chemical Equivalents" (1). The reader is urged to review that description. The present paper attempts to place this slide rule in context by describing its origins, as well as some of its predecessors and successors.

The concept of "A Synoptic Scale of Chemical Equivalents" was first presented in 1814 by the English chemist, William Hyde Wollaston (2). Chemical substances were arranged on a scale with distances proportional to the logarithm of their equivalent or combining weights, much as the value of π was marked on the scales of the more conventional slide rules of recent memory. A logarithmic slider, numbered from 10 to 320, allowed quick calculation, via the method of direct and inverse proportions, of the weights of substances reacting with one another, the quantity of products, or the relative proportions of elements in a compound. Wollaston's original design, measuring 12 by 2.5 inches, was marketed in London that same year. A contemporary called it "an instrument which has contributed more to facilitate the general study and practice of chemistry than any other invention of man" (3). It accelerated the acceptance of Dalton's atomic theory and promoted chemistry as a mathematical science.



William Hyde Wollaston (1766-1828)

Only a few of these original slide rules are still in existence. Some are in European museums (4). Only two are known to have survived in the United States and both are located at Harvard University. They are described as (5):

Pine; paper labels. L of each 12 in. Inscr. on face: Chemical Equivalents; lists of elements and compounds; Published by W. Carey, 182 Strand, Jan. 1, 1814. On slider: graduated, numbered scale. On back: By Special Appointment / [arms] / Thomas Jones, / (Pupil of Ramsden.) / ASTRONOMICAL / and / philosophical / INSTRUMENT MAKER / To His Royal Highness / The Duke of Clarence / 62 Charing Cross, / LONDON.

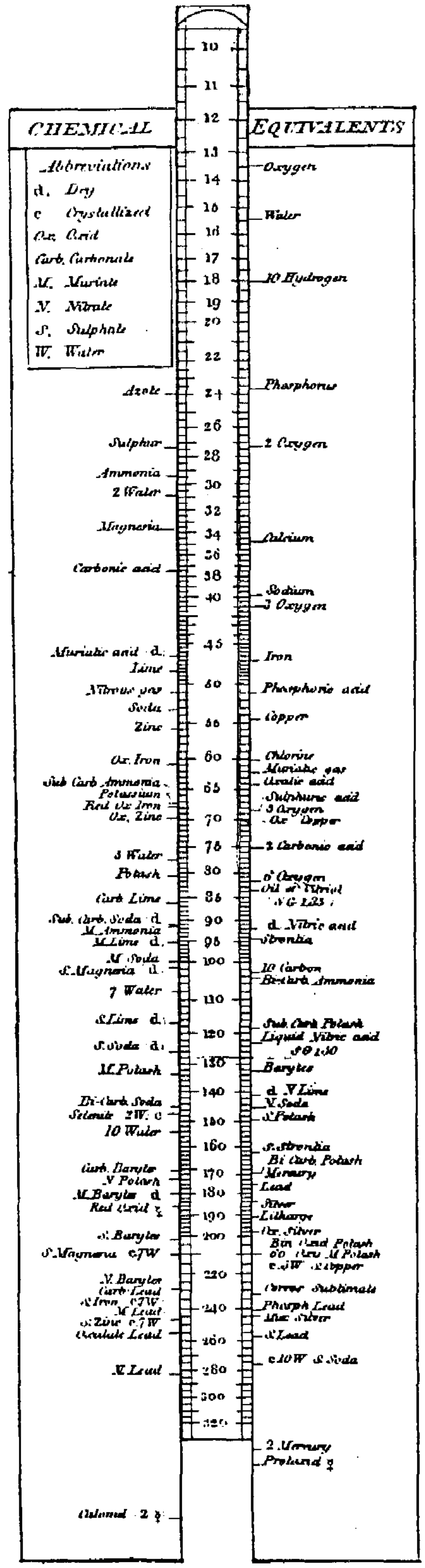
Drawings and discussions of the Wollaston slide rule appeared in several early American chemistry texts (6). Wollaston used oxygen = 10 as his equivalent (atomic) weight standard, but his choice was not accepted by all of his contemporaries. Thomas Thomson observed that Dalton, Philips, Henry and Turner preferred hydrogen = 1 as their standard, while he, Wollaston, Berzelius and "the greater number, if not the whole, of chemists on the continent" used oxygen = 1 or 10 (7). The 1818 edition of William Henry's *Elements of Experimental Chemistry* retained the original plate and explanation of Wollaston's scale in the Appendix, but used H = 1 in the text. Henry explained: "To reduce them [Wollaston's weights] to the standard adopted in this work, multiply by 7.5 and divide by 10" (8). Although Andrew Ure's 1821 *Dictionary of Chemistry* praised the concept of the scale, he concluded that it "is actually better adapted to the hydrogen unit than to the oxygen" (9). He also observed that such a scale would agree with Davy's system of proportions and Gay Lussac's theory of gaseous combination. Gradually H = 1 became the accepted standard since it avoided most fractional values. By 1830 most textbooks used the hydrogen standard.

Other chemical slide rules were also marketed in England. An improved version was published by David B. Reid in Edinburgh in 1826. It was issued with a 40-page pamphlet which discussed the concepts of definite proportions, gave examples for using the rule, and printed a long table of equivalent weights that could be used with the scale. This scale used H = 1 as the standard, but explained that the numbered slide did not start at 1 because the logarithmic distance would require a much longer slide. When hydrogen was used in a calculation, the slide was set at 10H = 10 and then the answer was divided by ten. Similarly, carbon used 2C = 12 (the accepted atomic weight of C at this time was six) and divided the answer by two. The Wollaston rule had also used this technique, but with different numbers. The dimensions of Reid's slide rule are not given in the pamphlet and it is not known if any examples still exist (10).

In 1841 William T. Brande, whose textbook used H = 1 as standard, recommended a chemical equivalent slide rule and accompanying table "made by Newman, No. 122 Regent Street, and Palmer, 60 Newgate Street" (11):

> The form of this [Wollaston] instrument, which I recommend to the student, is a box-wood scale, about two feet two inches long, consisting of a movable slider with a logometric [sic] line of numbers upon it, and a corresponding series of numbers upon the rule itself; upon the rule the simple substances are also arranged, each opposite to its respective equivalent ... to avoid perplexing the scale with a multiplicity of terms, a separate table accompanies it, containing a copious list of compound equivalents.

The "Newman" in question was probably John Newman, who was the official instrument maker for the Royal Institution, where Brande was Professor of Chemistry, and the co-inventor of the Newman-Brooke oxyhydrogen blowpipe described by Ross in a recent issue of the *Bulletin* (26). It is not known if this slide rule was the same as the Reid instrument or whether any copies still exist.



Wollaston's chemical slide rule as it appeared in his 1814 paper. This plate was reproduced in several introductory texts in the first half of the 19th century.

British-made slide rules were imported to the United States, but the Beck-Henry slide rule was the first to be manufactured in America. Produced in Albany, NY in 1827, it also used H = 1 as the standard. Fortunately some details of its development have survived.

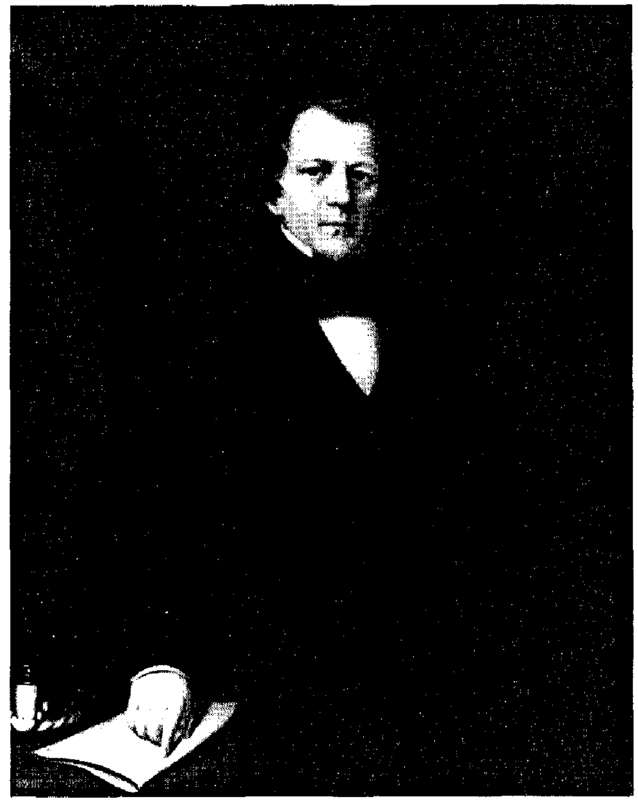
Joseph Henry (1797-1878) is noted for his contributions to electromagnetism and magnetic induction. He was immortalized when the present-day unit of inductance was named in his honor. As the first Secretary of the Smithsonian Institution, Henry established policies that resulted in the Institution's evolution into its present status as a world-renowned organization. Though his wide interests encompassed all sciences, he chose, in his own words, to confine his personal research efforts "to a course of study and investigation intermediate to pure Mathematics on the one hand and the more detailed parts of Chemistry on the other" (12).

From 1819 to 1822, Henry attended the Albany Academy, where he excelled in mathematics and science. He studied chemistry under T. Romeyn Beck using the 1816 edition of Samuel Parkes' *Chemical Catechism*, and performed so well that he was hired as Beck's lecture assistant in chemistry for the following academic year (1823-24). He then worked at various surveying and teaching jobs, including private tutor for the children of Stephen van Rensselaer, the wealthy patron of science. In 1826 Henry returned to the Albany Academy as Professor of Mathematics and Natural Philosophy. During the following six years he conducted many of his electrical experiments. Before he began that area of research, however, he and Lewis C. Beck collaborated in producing their own "Scale of Chemical Equivalents".

Lewis Caleb Beck (1798-1853) graduated from Union College in 1817 and obtained a medical license in 1818. He practiced medicine in Schenectady, St. Louis, and Albany before turning to teaching as a career in 1824. He taught chemistry and other sciences at Berkshire Medical Institution and Rensselaer Polytechnic Institute and was at Vermont Academy of Medicine in 1827 when work on the Scale of Equivalents began. He had undoubtedly met Joseph Henry while visiting his brother, T. Romeyn Beck, Principal of the Albany Academy and Henry's mentor in chemistry.

Henry may have gotten the idea of making the scale when he visited John Torrey at West Point in June 1826. He noted in his journal that "Dr. Torrey intends making one of Wallostons [sic] scales of chemical equivalents & to use Mr. Thompson's new attomic [sic] numbers" (13). Beck or Henry may have seen the newer Reid slide rule mentioned above, since a copy of Reid's *Directions* pamphlet can be found among Henry's surviving papers. The quotations below, however, strongly suggest that Henry and Beck struggled through their own design problems.

It is not clear who suggested the idea of manufacturing the scale, but Beck, in his autobiography, explained the division of labor and some of the complications (14):



Lewis Caleb Beck (1798-1853)

During this year (1827) Mr. Joseph Henry, then a Professor in the Albany Academy (now Secretary of the Smithsonian Institution) & myself, published "A Scale of Chemical Equivalents," which we constructed under the direction of Dr. Wollaston, the celebrated English Chemist. Our scale was nearly twice the length of Wollaston's & contained the names of more than double the number of substances. It was also more neatly made.

Mr. Henry arranged the divisions on the slider & furnished the account of the Mathematical Construction. I arranged all substances according to their atomic weight, & made the entire copy for the engraver, a work which of course required great accuracy.

The scale was engraved on Copper at considerable expense. One great difficulty in the way of accuracy of the Scale, was in attaching the printed part to the wood work, in such a manner that the exact ratios should be preserved in every position of the slider. The scale was at length engraved on bank paper & put on by Mr. Wilson, a globe maker, who was accustomed to this kind of work. Still many of them were, upon trial, found to be inaccurate & these were laid aside.

There were published first some 6 or 8 dozen of these Scales, & being considerably in demand, we prepared a Second edition. In this several new substances were introduced. But Wilson had, I think died in the mean time & we were obliged to employ another person to complete the work. He did not succeed very well - he, indeed, had no idea of the accuracy required, & the result was, that many of them were useless. Out of about 150, perhaps not more than 100 were fit for use.

From the expense & trouble which attended the construction of these scales, they were necessarily sold at a considerable price. I scarcely know whether the sales were sufficient to meet expenses, but this did not at that time enter into our calculation.

Unlike previous chemical slide rules, the Beck-Henry rule placed a printed "Description and Use" paper pasted on the back of the rule. Evidently Henry was overseeing the manufacturing process in Albany. In a letter of 15 April 1827, Beck sent Henry a suggested explanation to be put on the back of the scale. He continued (15):

You can add another illustration of its utility in analysis. One mistake I have noticed. Sulphate of Potash should be 88, I believe instead of 89 ... Look at this if you please, & correct the mistake, if it is one. By all means sign our names to the above "guide board" or any other which you may adopt.

The instrument was on the market at least as early as 11 September 1827, when Henry wrote a dealer (16):

I send by the bearer Mr. Robinson one Dozen Chemical scales. We cannot afford [to sell] them for less than one dollar & twenty five Cts a piece by the wholesale. You can therefore fix your price accordingly.

Joseph Henry (1797-1878)

On 21 September 1827, Henry wrote Beck (17):

As to the scale I have sent one doz. to Philadelphia and half a doz. to Dr. Hadley, also left one at Webster's and another at Dr. Meggs'; the woodwork of 1-1/2 doz more is completed and before they are varnished I will correct iodine with a pen. Finally the copy right [sic] which you concur in thinking necessary shall be secured.

Further errors were mentioned in a letter from Henry to John Torrey on 4 October 1827 (18):

I am much obliged to you for your notice of the errors on the scale. Sul. copper according to Thompson should have been 125 instead of 152 as it is on the scale. Silica was taken from Brand's tables (32) but I agree with you in thinking that silicon would have been better. These errors shall be corrected before any more impressions are taken from the plate and in the mean time should you discover any more will you be so good as to give us further notice.

The completed slide rule measured 18.5 by 2.75 inches and the slide scale was graduated from 8 to 330 (The scale began with oxygen, which on the H = 1 scale had at the time an accepted atomic weight of eight). Only one of these instruments is known to survive, a "second edition", dated 1828, at Transylvania University, Lexington, KY as reported in the article by Bodner mentioned earlier (1). Silliman's *American Journal of Science* reported both "editions" of the slide rule, noting that it was (19):

... strongly recommended by the adoption of hydrogen as unity ... we are happy to see it thus brought within reach of all students of chemistry in this country. It is justly observed that it is founded on the most important fact in the science, namely, that all bodies unite, chemically, in weights, or multiples of weights, that have the same constant ratio to each other.

Beck also made passing reference to the scale in his own 1831 text, *A Manual of Chemistry* (20):

The greatest number of chemists call hydrogen unity and therefore oxygen 8. This is much the most simple, and has been adopted in the scale of equivalents constructed by Professor Henry and myself.

The absence of further correspondence about the scale in the Henry papers suggests that the project ended in 1828. Both men continued their distinguished careers. Henry was Professor of Natural Philosophy at Princeton from 1832 to 1846 and director of the newly organized Smithsonian Institution from 1846 until his death in 1878. Beck continued to teach chemistry until his death in 1853, holding professorships at Vermont

Academy of Medicine, Rutgers, New York University, Middlebury College, Fairfield Medical College, Castleton Medical Academy and Albany Medical College.

Yet a second chemical slide rule was also marketed in the United States. This was announced in *Silliman's Journal* in 1829 (21):

> Messrs. Hedge & Co. of that place [Middletown, Conn.] have just commenced the manufacture of Wollaston's Scales. The one before us, says a writer in the American Sentinel, is the most finished specimen of workmanship of the kind we have ever yet seen; and the first attempt in box wood, to our knowledge, in this country. The Scale is 21 inches in length, by 3 and 2-10ths in breadth. The graduation is done by machinery, and is executed with a degree of beauty and accuracy we have never seen equaled ... Great care has been taken in the plan of arrangement of the chemical substances. The elementary bodies, metals, and metallic oxides, are arranged on one side of the slide, by themselves - the names of the metals are printed in larger type ... greatest care has been taken in consulting the latest tables of Drs. Henry, Thomson, and others so as to correct the errors of former tables.
>
> The scale, thus improved, was made at the suggestion and under the superintendence of Doct. J. Barratt ... The apparatus for effecting the graduations, is of a novel and ingenious kind, and is the invention of Mr. Hedge ...
>
> There are none manufactured in this country or elsewhere, that can compare with them, either in cheapness, in style of finish, in the number of subdivisions, or in accuracy of graduations ...

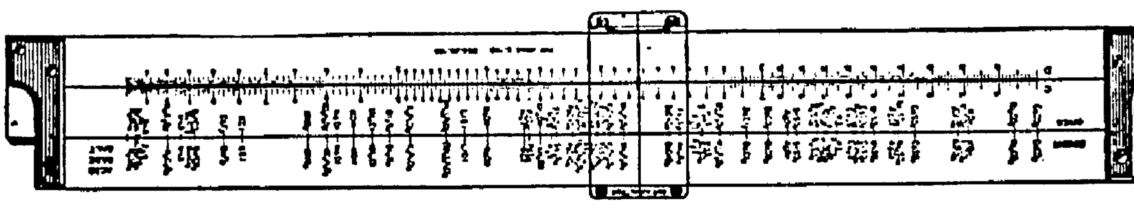
To the best of my knowledge no example of the Barratt-Hedge slide rule has survived.

A novel circular slide rule for equivalents appeared in the 1828 American edition of J. A. Paris's *Pharmacologia*. The plate on the inside of the front cover of this volume shows a circular logarithmic scale graduated in grains. In the center is an inner rotatable disk, 4.25 inch in diameter, marked with the names of common medicinals. Labeled the "Medicinal Dynameter and Scale of Equivalents", this circular slide rule allowed the user to calculate the quantity of active matter contained in any given weight of a medicinal or the weight of alternate substances that would contain the same quantity of active ingredient (22).

The popularity of the chemical slide rule, at least in conjunction with the teaching of elementary chemistry, seems to have waned by the second half of the 19th century. This was certainly implied by the comments of Benjamin Silliman, Jr. on the Beck-Henry scale in his 1874 survey of the history of chemistry in America (23):

> While in Albany with Dr. Beck, he [Henry] devised and published an improved form of Wollaston's sliding scale of chemical equivalents, in which hydrogen was adopted as the radix, a contrivance which is hardly known, even by name, to the present generation of chemists.

However, it was revived again in the period 1910-1950 in the form of the "Ashley Chemist's Slide Rule". This was designed for the use of analytical chemists involved in repetitive routine analytical procedures and carried the usual C, D, and CI scales of a regular slide rule for multiplication, division and reciprocals, as well as two scales of gauge points, marked by chemical formulas, corresponding to the molecular weights of the common reagents and precipitates used in gravimetric and volumetric analysis (24). A quick survey of laboratory supply catalogs strongly suggest that the chemical slide rule did not survive beyond the 1950s (25). But, if per chance, it did, there is little doubt that, like the mechanical slide rule in general, it did not succeed in weathering the onslaught of the portable electronic calculator in the 1970s.



The"Ashley Chemist's Slide Rule", circa 1914

References and Notes

Acknowledgment: The author would like to thank Dr. William B. Jensen for bringing the Greenaway booklet in reference 4, the Faraday book in reference 6, and the materials in references 5, 24, 25 and 26 to his attention, as well as for the information in the final paragraph of this article and on the identification of Henry's *Syllabus* in reference 12.

1. G. Bodner, "The Apparatus Museum at Transylvania University," *Bull. Hist. Chem.*, **1990**, *8*, 22-27.

2. W. H. Wollaston, "A Synoptic Scale of Chemical Equivalents," *Phil. Trans.*, **1814**, *104*, 1-22. See also P. Hinde, "William Hyde

Wollaston. The Man and his Equivalents", *J. Chem. Educ.*, **1966**, *43*, 673-5.

3. A. Ure, *A Dictionary of Chemistry*, T. & G. Underwood ... , London, 1821, unpaginated, under "equivalents".

4. See: F. Greenaway, *A Science Museum Illustrated Booklet. Chemistry. [Vol.] 1: Chemical Laboratories to 1850*, Her Majesty's Stationery Office, London, 1966, unpaginated (with photo); J. Van Spronsen, "Dalton en Wollaston", *Chem. Weekblad*, **1967**, *63*, 217-220 (with photo); A. Scott, "The Atomic Theory, with Especial Reference to the Work of Stas and Prout's Hypothesis", *J. Chem. Soc.*, **1917**, *61*, 288-311.

5. Anonymous, *Early Science at Harvard*, Harvard University Press, Cambridge, MA, 1969, p. 56; Another description, with a photograph, is in I. B. Cohen, *Some Early Tools of American Science*, Harvard University Press, Cambridge, MA, 1950, pp. 85, 166, Fig. 31, 32.

6. W. Henry, *The Elements of Experimental Chemistry*, James Webster, Philadelphia, PA, 1817, Appendix p. lxv-lxviii, Plate XI; W. Henry, *The Elements of Experimental Chemistry*, Robert Desilver, Philadelphia, PA, 1819, Vol. 1, Appendix p. i-iv and Vol. 2, Plate XI; J. Gorham, *The Elements of Chemical Science*, Cummings and Hilliard, Boston, MA, 1819, Vol. 1, pp. 54-57 with Plate and 539-542; J. Cotting, *An Introduction to Chemistry*, Charles Ewer, Boston, MA, 1822, pp. 31-34 and Plate 1; W. J. Macneven, *Exposition of the Atomic Theory of Chymistry*, Grattan and Banks, New York, NY, 1819, pp. 62-73. The Wollaston slide rule is also mentioned in the British and American editions of Michael Faraday's book *Chemical Manipulation*, see M. Faraday, *Chemical Manipulation*, Carey and Lea, Philadelphia, PA, 1831, pp. 581-593.

7. T. Thomson, *The History of Chemistry*, Henry Colburn and Richard Bentley, London, 1831, p. 297.

8. W. Henry, *Elements of Experimental Chemistry*, Robert Desilver, Philadelphia, PA, 1819, Vol. 2, p. 420.

9. Reference 3, unpaginated, under "equivalents".

10. D. Reid, *Directions for Using the Improved Sliding Scale of Chemical Equivalents; with a short Explanation of the Doctrine of Definite Proportions*, Maclachlan and Stewart, Edinburgh, 1831, 40 pp. (First edition was 1826, Edinburgh, publisher unknown.) This pamphlet was included as Part II of Reid's *Elements of Practical Chemistry...*, Maclachlan and Stewart, Edinburgh, 1830, pp. 408-442.

11. W. Brande, *A Manual of Chemistry*, John W. Parker, London, 1841, Vol. I, p. 237.

12. N. Reingold, *The Papers of Joseph Henry*, Smithsonian Institution Press, Washington, DC, 1972, Vol. 1, p. 435. Henry's other activities in chemistry were minor. In 1832 he collaborated with T. R. Beck and Lewis C. Beck in a public lecture course in chemistry at Albany, but his contribution emphasized physics while Lewis Beck taught the chemistry. In 1833 he taught John Torrey's summer chemistry course at Princeton while Torrey was in Europe. The *National Union Catalog* contains an erroneous listing, citing Joseph Henry as the author of *Syllabus of a Course of Lectures on Chemistry* (40pp., no date, no place, no publisher). This imprint was actually the work of William Henry. A comparison of the *Syllabus* with Henry's 1801 *An Epitome of Chemistry* reveals an identical outline, even with peculiar spellings. The *Syllabus* is also identified as the work of William Henry in J. Partington, *A History of Chemistry*, Macmillan & Co., London, 1962, Vol. 3, p. 825.

13. *Ibid.*, p. 159.

14. *Ibid.*, p. 195. The collaboration is also described in C. Van Cortlandt, *Trans. Med. Soc. County of Albany, N.Y. (Albany Med. Annals)*, **1864**, *1*, 292-302.

15. *Ibid.*, p. 185. The explanation on the back of the scale is quoted in its entirety in Reingold, Reference 12, pp. 191-194 and partially in Reference 1, p. 24-25.

16. *Ibid.*, p. 196.

17. *Ibid.*, p. 197.

18. *Ibid.*, p. 199.

19. [B. Silliman], "Intelligence and Miscellanies," *Am. J. Sci.*, **1828**, *14*, 202-203; **1830**, *18*, 385. The quotation is from the 1830 citation.

20. L. C. Beck, *A Manual of Chemistry*, Webster and Skinners, Albany, NY, 1831, p. 34.

21. [B. Silliman], "Intelligence and Miscellanies," *Am. J. Sci.*, **1829**, *16*, 371-2.

22. J. Paris, *Pharmacologia*, E. Duyckinck, Collins & Co..., New York, NY, 1828, inside front cover and pp. 243-244. The disk of substance names was color coded with hand applied water colors.

23. B. Silliman, *American Contributions to Chemistry*, Collins, Philadelphia, PA, 1874, p. 71.

24. A brief description of the Ashley slide rule can be found in J. E. Thompson, *A Manual of the Slide Rule: Its History, Principle and Operation*, Van Nostrand, New York, NY, 1930, pp. 211-212.

25. Thus, for example, the 1914, 1929 and 1937 catalogs for the E. H. Sargent Co. of Chicago all carried the Ashley chemical slide rule, but it was no longer offered in the 1967 catalog. It was also listed in the 1919 catalog of the Scientific Materials Co. of Pittsburgh, the 1928 catalog of the Wilkens-Anderson Co. of Chicago, and the 1936 catalog of the Eimer and Amend Co. of New York, but it is missing from the 1912 Eimer and Amend catalog and the 1967 catalog for Fisher Scientific of Pittsburgh. The 1936 Eimer and Amend catalog also carried the "Nestler chemical slide rule".

26. S. Ross, "Unpublished Letters of Faraday and Others to Edward Daniel Clarke", *Bull. Hist. Chem.*, **1991**, *11*, 79-86.

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NOTICE: If any of our readers know of other locations of additional examples of any of the chemical slide rules mentioned in this article, both the author and the editor would appreciate hearing from you.