Chemical Slide Rules: Their History and Use

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As a chemistry teacher, I have a special interest in chemical and chemistry related slide rules. The number of these models made is quite small, but there is a fair amount of variety in those that were made. What I hope to do in this article is summarize a bit of the history of chemical slide rules, the different models that were made, how each was designed to be used, and describe the reasons why many chemical calculations, while seeming to be a natural application for the slide rule, may not have been all that widely used.

Early History

By the early and mid 1800's, the relative weights of many elements were known. Since no knowledge of isotopes yet existed (James Chadwick did not discover the neutron until 1932), averages of the isotopes would have been used and given the limitations that existed in making accurate measurements, there were many inaccuracies. Although by the time Mendeleev began organizing his early periodic tables, at least sixty elements were known and his atomic weights were accurate, in most cases to at least the nearest whole number [1]. W. Cary created the first chemical slide rule in 1814, based on chemical equivalents. In 1820 William Wollaston made a slide rule in which the equivalent weights of elements and compounds were arranged logarithmically to allow prediction of amounts of reactants and products in reactions. Conrad Schure has described his example of this slide rule previously [2].Wollaston's slide rule listed approximately 100 chemical species (compounds or element and their relative weights). In these early slide rules, the idea of a specific atomic or molecular weight was still in its infancy and the standard was based on oxygen = 10; although many people preferred using hydrogen = 1 as a standard. Many of these inaccuracies arose due to a lack of understanding of which elements were diatomic and which were not. However, given the proportional nature of chemistry, these rules would have been quite accurate, given the available numerical information. Equivalent weights were widely used and, with no notion of atomic structure, were quite applicable. A sketch of Wollaston's slide rule can be found in [3, 4], and, in this example, oxygen is set at 13.5; I do not know why. A perusal of some common chemicals shows that ammonia has an equivalent weight slightly less than that of water (to the nearest whole numbers the molar masses are 17 and 18 grams/mole respectively) and sulfur has a weight almost exactly double that of oxygen (32 vs. 16 grams/mole based on the modern periodic table). In the 1830's the weight of hydrogen was accepted to be 1, carbon to be 6, and oxygen to be 8. Until a better understanding of the atomic theory came to be, these inaccuracies would still appear in textbooks and reference manuals.

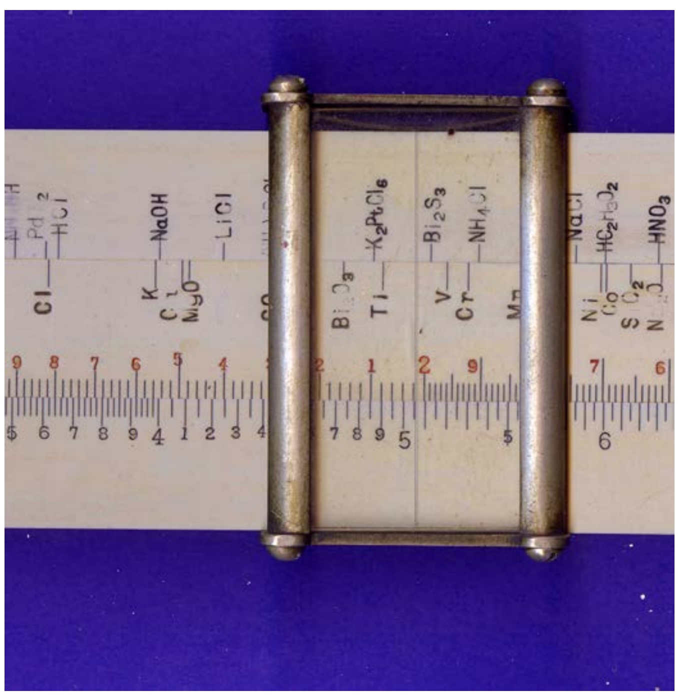

FIGURE 1.
CLOSE UP OF EARLY MODEL K & E 4160, showing chemical formulas as gauge marks, C and D scales, and column cursor

More Modern Chemical Slide Rules

In this section I plan to summarize information about several of the modern chemist's slide rules, describing features unique to each one, how they were designed to be used, and, where possible, providing scans of the rules. These will include the Keuffel and Esser 4160, Hemmi 257 (essentially equivalent to the post 1491 and Hemmi 257 L), Nestler 330, Unique Chemical, Faber-Castell Verlag Chemie, and Flying Fish 1017. Concise had many slide rules with chemical data inserts (such as the 600CE) and charts but as far as I can tell not with scales that included gauge marks that referred to molar masses or atomic weights.

Keuffel & Esser 4160 Chemist's Duplex Slide Rule

The Keuffel and Esser model 4160 Chemist's Duplex slide rule was first introduced in 1913. It is listed as an addendum to the 1913 catalog and cost $8.00 [5]. The molecular formulas for 46 salts and10 acids are on the A and B scales of the frame. On the back are symbols of 42 elements and 37 oxides of elements in place of the A scale and the same elements and oxides on the BI scale. This rule was primarily designed for stoichiometric calculations. The slide rule was newsworthy enough to be described in Metallurgical and Chemical Engineering in March of 1914 [6]. Each of the atomic or molecular formulas listed essentially serves a gauge mark for the proper molar mass of the substance. Interestingly, there is no gauge mark at 22.4, the number of liters one mole of an ideal gas occupies at standard temperature and pressure, a widely used number in many stoichiometric calculations involving gases. For nonstandard conditions, one would then apply a gas law involving temperature and pressure ratios (such as the combined gas law), a calculation for which the slide rule is ideal. There is also no mark corresponding to 6.02, to aid in calculations using Avogadro's Number, 6.022×10^{23}. The rationale for the use of a slide rule for chemical calculations is based on the fact that chemicals react with each other in specific whole number ratios, defined by the coefficients of the balanced equations.

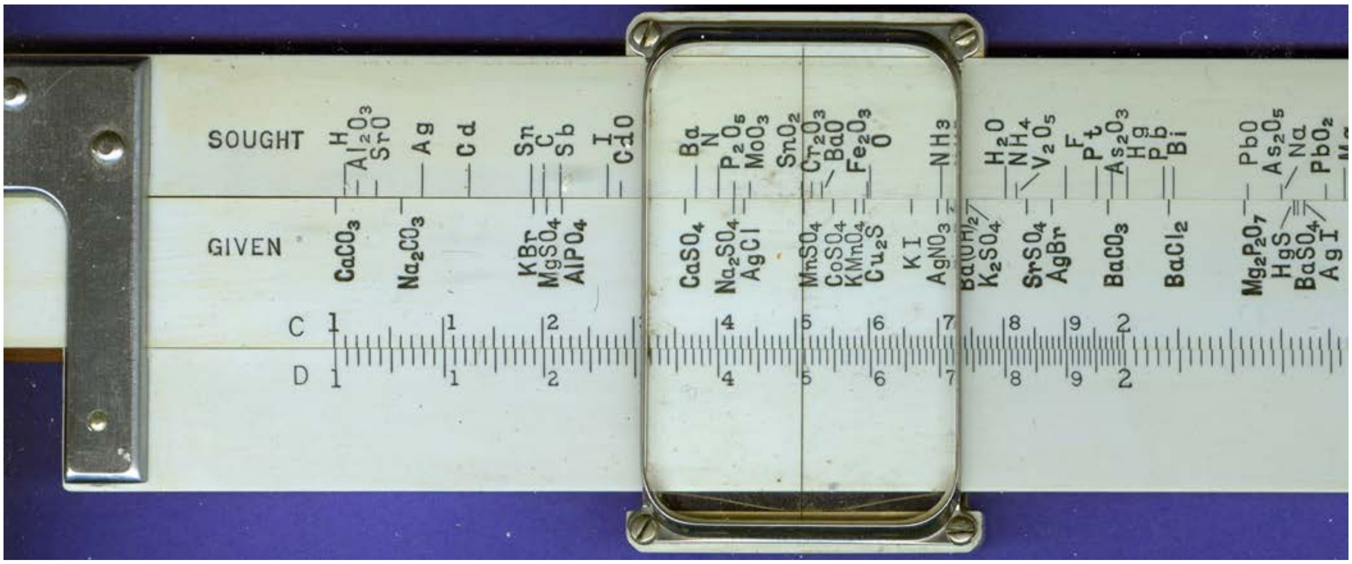

FIGURE 2.
A LATER MODEL K & E 4160 SLIDE RULE,
showing the "given and sought" gauge marks for acids, bases, and salts

Consider the reaction of sodium hydroxide and sulfuric acid shown below:

$$2\ NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2\ H_2O \qquad (1)$$

A typical stoichiometric calculation might ask one to determine the mass of sulfuric acid, H_2SO_4 that would react with 80 grams of sodium hydroxide, NaOH. The calculation to be done would be set up as follows (using dimensional analysis or the factor label method as is commonly called in many textbooks).

$$80\text{ g NaOH} \times \frac{1\text{ mole NaOH}}{40\text{ g NaOH}} \times \frac{1\text{ mole }H_2SO_4}{2\text{ mole NaOH}} \times \frac{98\text{ g }H_2SO_4}{1\text{ mole }H_2SO_4}$$

$$= 98\text{ grams }H_2SO_4. \qquad (2)$$

Given the proportional nature of many stoichiometric calculations, a slide rule seems ideal for these calculations. The description in the manual (7) is nothing more than performing a series of proportions in sequence, except that rather than specific numbers, one aligns the formulas of the chemicals known and being sought. One could just as easily line up use 40 (the molar mass of NaOH) as use the marking labeled NaOH. Most practicing chemists would know common molar masses of the chemicals they used almost by heart.

Another common calculation is to determine the percent by mass of an element in a compound. For example, to determine the mass of lead in a given sample of lead (II) chromate one would divide the mass of a mole of lead (207.2 g) by the molar mass of lead (II) chromate (323.2 g), giving 64.1 %, which could then be multiplied by the mass of lead (II) chromate to determine the mass of lead that could be obtained from the sample. For any chemical listed on the slide rule, there was no need to calculate the molar mass.

Similarly, gravimetric and other stoichiometric factors could be obtained from molar mass ratios. Unfortunately, many calculations of molar mass involving addition (one adds the individual masses of the atoms in the compound) and so for any chemical not listed, one would have to do some combination of "add the mass of 3 lead atoms (locating lead on the A scale) to the mass of 2 phosphorus atom to 8 times the mass of one oxygen atom." I suspect this was not an issue as most chemists would readily determine a molar mass from any periodic table and for compounds they worked with frequently, they would know the molar mass from such frequent use.

The chemists slide rule could also be used for volumetric analysis, or stoichiometric calculations involving volumes and concentrations. For example, in the reaction between sodium hydroxide and sulfuric acid (see equation 1) one could solve a problem such as: What volume of 0.5M sulfuric acid is needed to neutralize 45.0 ml of 0.65M sodium hydroxide?

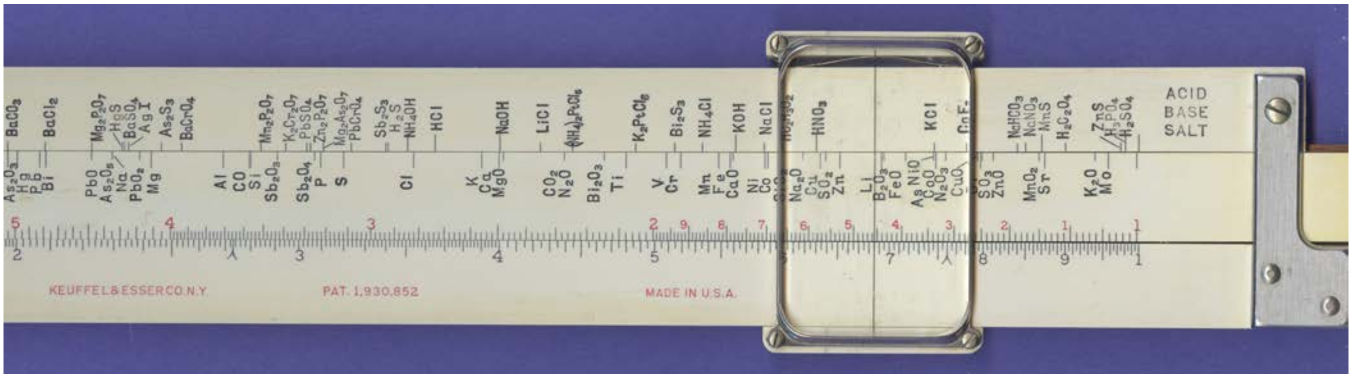

FIGURE 3.
THE LATER MODEL KEUFFEL AND ESSER 4160,
showing the reverse side which features more elements and their oxides

The equation would be set up as follows:

$$0.65 \text{ moles NaOH} \times \frac{0.045 \text{ L NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mole } H_2SO_4}{2 \text{ moles NaOH}} \times \frac{1 \text{ L } H_2SO_4}{0.5 \text{ moles } H_2SO_4}$$

$$= 0.0293 \text{ L} = 29.3 \text{ ml } H_2SO_4 \qquad (3)$$

Similarly, one could perform calculations involving combinations of mass and volumes of solutions.

From having worked through some problems with my own 4160's I find them to be a clever idea, but probably more work to use the actual markings, as opposed to simply setting the problem up and then solving as a series of multiplication and division steps. In fact the manual even states that "…In many cases the operator may solve problems directly with the rule, but when the problem is involved, it is better to write down the mathematical expression" [7, p. 25].

The 4160 slide rule was listed in the Keuffel and Esser catalog through 1941, costing $12.00. I do not think it was a big seller for K & E, although I have no data to support my conjecture. In the 1936 educational products catalog [8] the slide rule is not listed, suggesting it was not something K & E thought would be widely used by students or their teachers.

In comparing my examples of early and later examples (a span of about 25 years) of this slide rule, apparently the chemical species listed did not change much. I see the addition of CO (= 28) but no other additions. This may have been to accommodate some calculations involving the carbonyl group and metals, wherein the CO group was acting as the ligand. It may have been there to provide a molar mass for carbon monoxide, but one would then expect a similar mark at 44 for carbon dioxide, CO_2.These functional groups became increasingly important in the first half of the 20th century [9], suggesting their addition to this slide rule may have been at least partially motivated by that fact. I suspect that as common as CO groups are in organic chemistry, that was not the main application, as this is a slide rule with very few organic substances listed.

I count 52 items on Rod Lovett's site [10] between October 1999 and October 2011 that I think are K & E 4160 slide rules. All may not be unique, but I think this suggests that

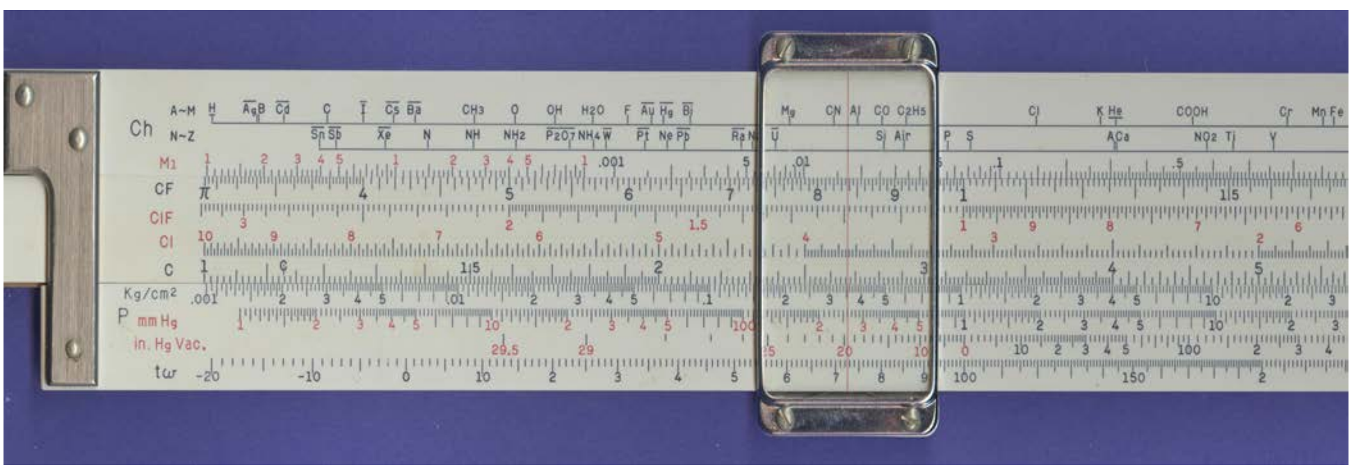

FIGURE 4.
FRONT OF HEMMI 257 CHEMICAL ENGINEER'S SLIDE RULE
Note the scales for chemicals at the top and pressure unit conversions and water vapor pressure at the bottom

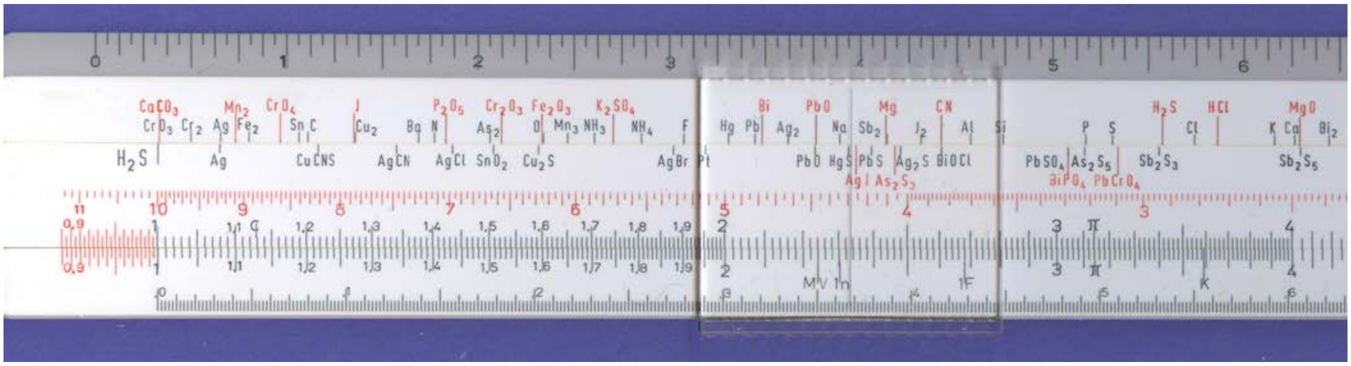

FIGURE 5.
FRONT OF NESTLER 0330 CHEMIKER SLIDE RULE

there were not large numbers of this slide rule produced.

Hemmi 257 Chemical Engineering Slide Rule

The Hemmi 257 slide rule was produced from 1952 to 1967 and was replaced by the Model 257L, which was made in 1971. For the purpose of this article these slide rules (as well as the Post 1491, which was made from 1957-1967 and the Hughes-Owens 1770, which was made in about 1958) are equivalent [11] both in terms of the scales on the slide rule and the chemical species listed. Thus, these rules were made well after Keuffel & Esser stopped producing the 4160 Chemist's Duplex. This slide rule was designed for wider range chemical engineering calculations than the Keuffel and Esser slide rule, as well as some stoichiometric calculations.

The gauge marks, listed in the Ch scales (divided A-M and N-Z), include 52 elements (the first 20 elements, 18 transition elements, and the most common "representative elements", as well as Radium and Uranium). Interestingly, note that the Noble Gases are included, despite their essentially inert nature (the first Nobel gas reaction was not even reported until 1962 [12], well into the "lifetime" of this slide rule) meaning that one would do no calculations involving reactions with the Noble Gas gauge marks. There are also gauge marks for a variety of functional groups (such as the phenyl group, C_6H_5 and the methyl group, CH_3) and common ions (such as hydroxide, OH^-, and phosphate, PO_4^{-3}). Eighteen such functional groups are included.

The manual describes several uses of this slide rule including finding molar masses of compounds, essentially using the gauge mark to locate an atomic mass, repeating this process for each atom, and then adding these up. There is no way to avoid the necessity of addition, meaning that at some point the operator would have to do a calculation in his or her head or on paper. Given the familiarity practicing chemists have with atomic weights and molar masses of common chemicals, I doubt this was a hindrance. Thus, the slide rule was probably less of a time-saving device.

The main functions of the Hemmi 257 slide rule are in a variety of unit conversions. Scales on the slide rule allowed ready conversion between Fahrenheit, Celsius, Kelvin, and Rankine scales. The Rankine scale was used in some specialized fields but is not used currently in thermodynamics and recent use has been minimal. There are also scales for pressure conversion, with units of kg/cm^2, mm Hg (also known as Torr), inches Hg, and atmospheres. The t_w scale was used to find the vapor pressure of water (and also the boiling point of water at various pressures).

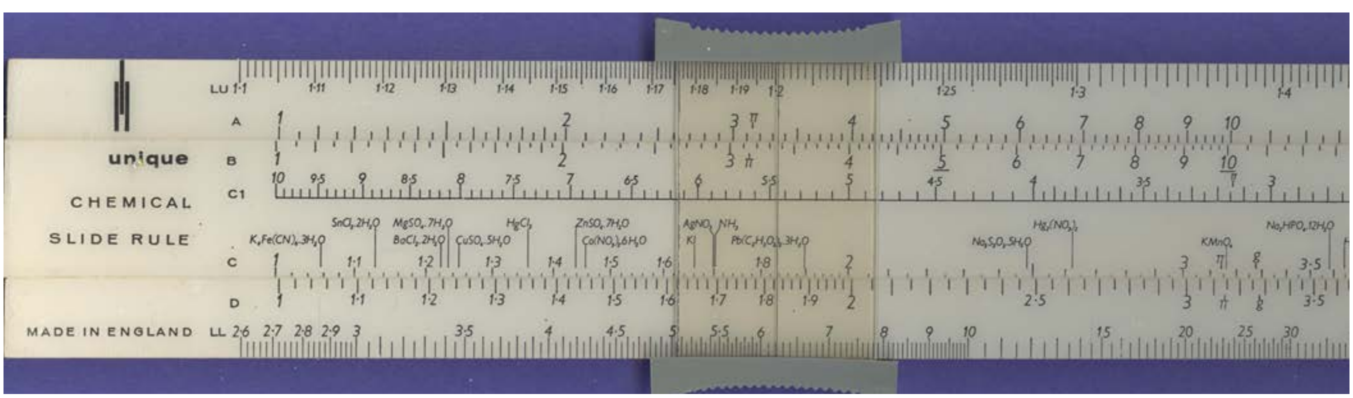

FIGURE 6.
FRONT OF UNIQUE CHEMICAL SLIDE RULE
Note the small number of chemicals listed (one third of which are hydrates)

The slide rule has scales for converting mole fraction, mass percent, and volume fraction, based on knowledge of densities. Knowing vapor pressures of liquids, this slide rule could also be used to find the composition of a vapor above a mixture of volatile liquids, an application of Raoult's Law.

The Hemmi 257 slide rule had many convenient conversions available, most of which may well have been easier to perform on simple nomographs or slide charts. Its utility for stoichiometric calculations is much more limited.

I find 73 examples of the Hemmi 257 or 257L on Rod Lovett's site [10], as well as 41 examples of the post 1491 and 3 examples of the Hughes-Owens 1770. These numbers are larger than those for the Keuffel and Esser slide but that could be either to a greater utility or the fact that they are much newer, and therefore less likely to have been lost or damaged.

Nestler Number 0330 Chemiker Slide Rule

The Nestler 0330 slide rule operates much the same as the Keuffel and Esser 4160 slide rule. It is designed to perform stoichiometric calculations and to do percent analyses. The slide rule is listed in the 1967 catalog [14], but I am not able to determine the range of years in which it was sold. The scales that show gauge marks for chemical species are quite crowded and contain about 150 chemicals in total. The back of the slide rule lists atomic weights and molar masses for many of the same compounds. I note that there is a gauge mark for H_2S at the left index mark, which does not correspond to its molar mass of 34. H_2S is also listed at the proper location along the scale, between S (32 grams/mole) and Cl (35.5 grams/mole).

I do find odd the listing on the back multiples of many mass-

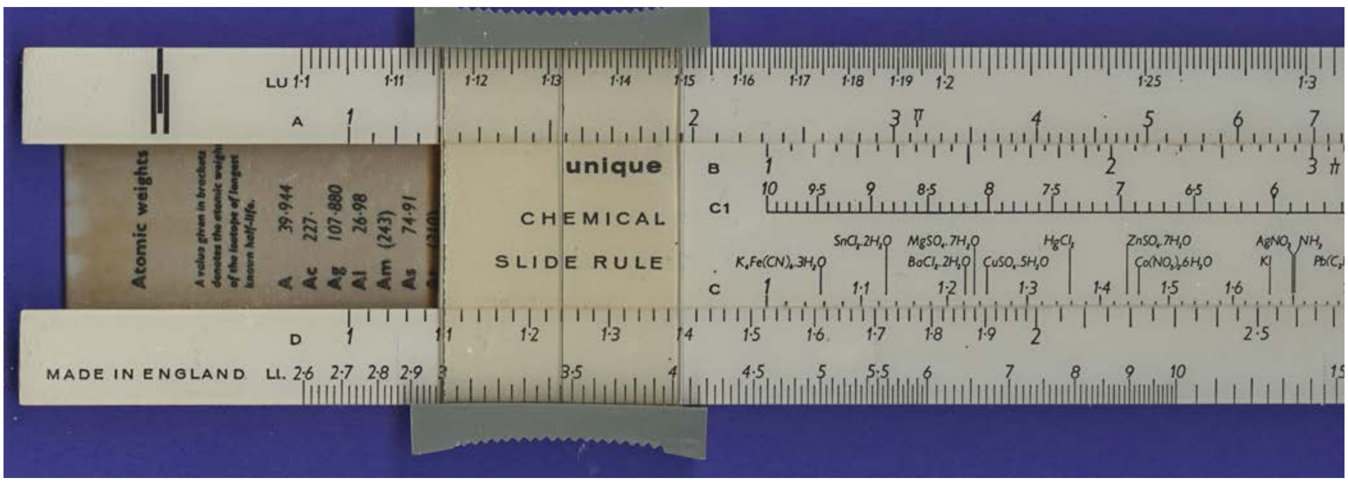

FIGURE 7.
THE WELL OF THE UNIQUE CHEMICAL SLIDE RULE
Note the Pre-1957 use of "A" for Argon

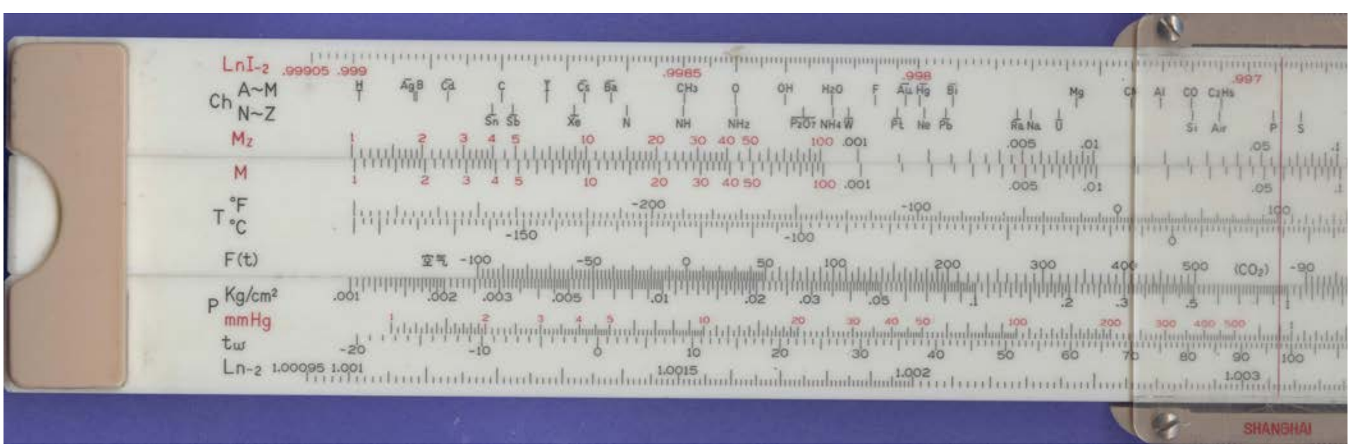

FIGURE 8.
THE FLYING FISH 1017 SLIDE RULE
Notice how the list of chemicals on the Ch scales is identical to that of the Hemmi 257

es (such a 2 O, 3 O, etc and 2 Cl through 5 Cl). This seems to be useless information given that a slide rule could easily be used to perform these calculations. These are listed to more significant figures (in many cases five) than one could locate on a slide rule as well. I count 27 of these rules on ebay since October of 1999, most from the German eBay site [10].

Unique Chemical Slide Rule

The Unique Chemical Slide Rule lists only 33 chemical species and 11 of them are hydrates. Calculating the percent of water in a hydrated crystal is a fairly common calculation, yet the slide rule does not have water marked on the scale with other chemicals. The well of the rule lists atomic weights alphabetically from A, an abbreviation used for Argon up until 1957 [16] to Zr. This allows this particular example to be date to prior to 1957. The back of the slide rule shows atomic numbers (not weights) of elements up to atomic number 102 (Nobelium). Element 103, Lawrencium, was discovered in 1961 [15] and would have taken a few years to appear in books and in data tables. Atomic numbers would not be involved in any calculations and other than for completeness, I do not see any reason they would be on a slide rule. The roster of chemicals on this slide rule is hard to explain and with so few, many stoichiometric calculations would not likely to have been performed with this slide rule. I note a total of 3 examples of slide rule on eBay from 1999 to the present, and at least one of those was an electro slide rule that had some chemical data included [10].

Flying Fish 1017

The Flying Fish Model 1017 slide rules looks to be very similar to the Hemmi 257. In fact, the list of chemicals on the A-M and N-Z scales is identical. This rule has Fahrenheit and Celsius scales, but not a Kelvin scale. It also includes many of the same scales for pressure conversions, concentration unit conversions, and calculations involving vapor pressure. Who "borrowed" from whom I cannot say, although given the dates of operation of the companies I suspect Hemmi was making this type of slide rule first. On eBay, I note a total of 8 examples of this slide rule having been sold [10], suggesting it was not at all common.

Faber Castell Verlag Chemie

This is an extremely rare slide rule. I note only 2 examples having been sold on eBay in the last 12 years [10]. One other was auctioned at the recent International Slide Rule Meeting in Cambridge MA. The C scale (molvol, labeled "x") on the right edge lists molvol (22.4L, the molar volume of one mole of an ideal gas at standard temperature and pressure, as well

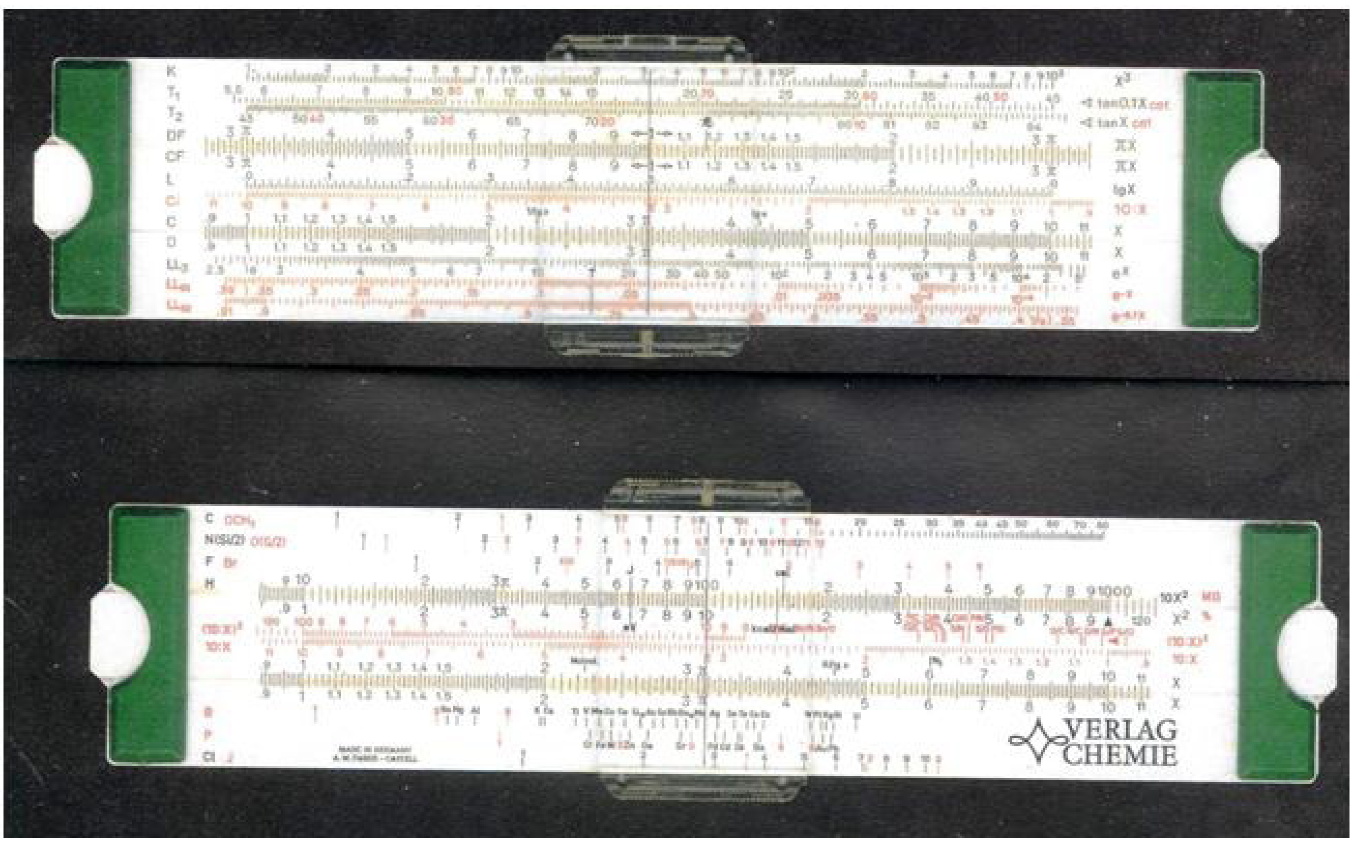

FIGURE 9.
THE FABER CASTELL VERLAG CHEMIE
(Scan generously provided by Richard Smith Hughes)
Note the cursor lines for both joules and calories

FIGURE 10.
THE ARISTO 630
(image from reference 16, used with the permission of David Thompson)
Note the complete listing of atomic weights, but not the inclusion of any compounds

as NL, an abbreviation for Avogadro's Number, 6.02 x 10^{23}.

Scales include listings for a large number of elements and compounds, and all scales are based on the 1961 atomic weights, which use the mass of the isotope Carbon-12 = 12.0000 [17]. The slide rule is designed to allow one to calculate a wide range of molecular weights, up a molar mass of 1300 grams/mole. However, as with any slide rule of this type, after finding the mass of for example, 6 carbon atoms, 13 hydrogen atoms, and 1 oxygen atom, these would still have to be added together. The cursor has lines to allow for conversions between calories and joules and between extinction and transmittance in spectroscopic work. The large number of elements listed on the slide rules make this slide rule well suited for determinations of percent mass of an element in a compound and for determination of empirical formulas.

The only other example of which I am aware is the Aristo 630. I have never seen one, nor have any been on eBay in the past 12 years [10]. Some scans of a manual and one example are available [17]. The rule has what appears to be the atomic weight of every element up to an including Curium, Cm. No compounds are included making the rule's utility for chemical calculations quite limited.

I am not aware of other chemical slide rules that were made. The subject of slide charts to predict reactions and chemical formula predictors, along with calculations for specialized chemical calculations, such as hardenability of alloys, is best left for a later article.

While they were not common and in some cases of limited use, chemical slide rules have been in use for a long time and must have been worth the time and effort that went into making them. The question as to how many were made and how widely they were used remains unanswered. As Joe Soper communicated to me "I only know they were a specialty type rule and only a small number were produced in Hoboken. I don't believe they were produced as part of the regular schedule on the floor and were engraved as ordered in Harry Schneider's Department 7L along with other low volume rules" [18]. As someone who has taught chemistry and done chemistry calculations for many years, my own personal feeling is that while the rules are very clever, they would in many cases have been more trouble to use than the old-fashioned paper and pencil method of calculating. The specific chemicals each rule did or did not have made that rule limited in the range of calculations it could perform. In some cases an entire slide rule seems like overkill, since most chemists are very familiar with the formulas and molar masses of common chemicals. Add in the fact that one was limited to only 3 significant figures in most cases and I think that the novelty of these slide rules did not justify the cost of purchasing one or the trouble to learn how to use one.

References

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18. Joe Soper, Personal Communication, 4 November 2011.

Thanks to Richard Smith Hughes for providing scans of the Faber Castell Verlag Chemie rule and to Joe Soper for his insights into the possible quantities of the K & E 4160 rules. Mike Frye provided me with the information from reference 6. I also appreciate permissions granted by David Thompson and Mike Konshak.