visits by laymen and professionals alike. A tour includes interpretations by well-informed guides as well as a Swedish documentary film dealing with a small blast furnace shut down at the beginning of this century.

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WHATEVER HAPPENED TO THE MICROCRITH?

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Until quite recently, authors of introductory chemistry texts have always been careful to point out that atomic weights are relative rather than absolute and that they consequently have no units. However, the use of the words relative and absolute in this context is in some ways unfortunate. The intent was, presumably, to point out that, although the masses of atoms could be determined relative to one another by arbitrarily selecting a particular atom as a standard, their values in grams or in other conventional mass units was unknown or, at best, only approximate. The problem, of course, is that *all* conventional mass scales are in reality relative and involve comparison with an arbitrarily selected standard whose use depends on the twin virtues of reproducibility and convenient size. Thus, in practice, the only thing which distinguished the so-called relative atomic mass scale from the conventional metric scale was a failure to give the former unit an explicit name, and the so-called dichotomy of relative versus absolute resolves itself into one of determining an accurate conversion factor between the two units.

It was apparently not until 1961 and the adoption of the ^{12}C = 12 scale and the unified atomic mass unit (u) that chemists came to accept this point of view - apparently - because, in fact, a little-known atomic mass unit called the *microcrith* had actually been introduced into chemistry 90 years earlier and had enjoyed a brief, but limited, existence in American high school chemistry texts during the last quarter of the 19th century. The origins of this unit can, in turn, be traced back to an earlier unit called the *crith*, which was introduced into chemistry by the German chemist, August Wilhelm Hofmann (1818-1892), in the 1860's.

Though German-born and educated, Hofmann spent nearly two decades (1845-1864) as Professor of Chemistry at the Royal College of Chemistry in London. When he finally returned to Germany in 1865 to accept a position at the University of Berlin, his former students at the Royal College

August Wilhelm Hofmann

requested that he issue his famous course of lectures at the College in book form. Hofmann complied - at least in part. Deleting the later descriptive lectures, he published the first 12 introductory lectures, dealing with the theory of chemistry, in 1865 as a small volume entitled *Introduction to Modern Chemistry: Experimental and Theoretic* (2). This was quickly translated into German and, in this form, went through many subsequent editions and revisions (3).

As the word "modern" in the title suggests, Hofmann felt that chemistry had recently undergone a significant transformation, the most important components of which were the consistent and widespread use of Avogadro's hypothesis and gas densities to arrive at a self-consistent set of atomic and molecular weights and the emergence of the concept of valence. Indeed, it was in this very volume that Hofmann introduced the word valence into the chemical lexicon in the form of its longer variant - quantivalence (4).

The primacy of gas densities in the development of a self-consistent theory of chemical composition was emphasized by Hofmann throughout the book. Beginning with the volumetric decomposition and synthesis of the simple hydrides H_2O, NH_3 and HCl, the laws of chemical combination by volume were developed first. Combination by weight was then introduced via the use of gas densities. Selecting the density of hydrogen at STP as a standard, Hofmann assigned each element and compound a real or hypothetical (for nonvolatile species) relative "Volumgewichte" at STP which allowed him to translate the volume formulas and reaction equations developed earlier in the book into the corresponding weight or mass relations.

In order to facilitate the use of his relative "Volumgewichte" or specific gravity scale, Hofmann further proposed that it be measured in units of *criths*, a name derived from the Greek word for a barleycorn, in analogy with the word *grain* - a commonly used mass unit in pharmacy. Thus, his standard of one liter of hydrogen at STP, with a conventional mass of 0.0896 g, weighed one crith on his new scale, a liter of chlorine weighed 35.5 criths, a liter of oxygen weighed 16 criths, etc.

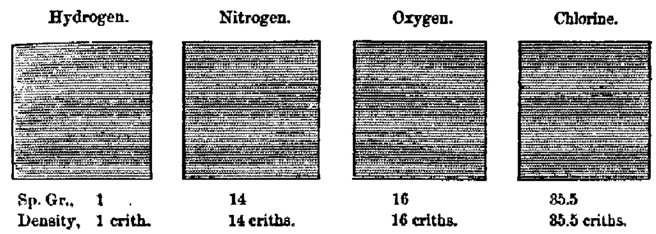
Having finally developed a self-consistent experimental basis for composition by both volume and mass, Hofmann completed his lectures by introducing the hypothesis of atoms and molecules, eventually reaching the conclusion that a self-consistent set of atomic and molecular weights could be assigned which were, for the vast majority of substances, twice the numerical value of their experimental "Volumgewichte" measured in criths.

From Hofmann's book, the crith quickly made its way into a number of contemporary British textbooks (5), the most notable of which was Edward Frankland's *Lecture Notes for Chemical Students* (6) and from there, if we are to believe the acknowledgments in the introduction, to the United States and into Josiah Parsons Cooke's textbook, *First Principles of Chemical Philosophy*, published in 1868 (7). Cooke (1827-1894), who was Erving Professor of Chemistry and Mineralogy at Harvard, had pioneered the teaching of quantitative stoichiometric calculations to beginning students in chemistry (8) and, in his *Chemical Philosophy*, he further introduced example calculations involving the use of the crith. Though he worked these as a series of proportions, they were, in terms of the modern technique of unit cancellation, equivalent to entering and leaving the following sequence of conversions (where c stands for crith) at whichever points were required by the problem in question:

Josiah Parsons Cooke

$$g_A \leftrightarrow c_A \leftrightarrow L_A \leftrightarrow L_B \leftrightarrow c_B \leftrightarrow g_B$$

Implicitly, this meant that one was reading the coefficients in an equation or formula in liters and was consequently using a "mole-like" unit of comparison whose numerical value was determined by the number of molecules in one liter of an ideal gas at STP. The inconvenience, of course, was that the "Volumgewichte" represented by a formula was not equal to



An illustration of the crith concept from Cooke's 1874 text (9)

its atomic or molecular mass but to half its value in units of criths.

Cooke explicitly addressed this problem in 1874 in a book of popular lectures on chemistry which he had delivered at the Lowell Institute in Boston two years earlier (9). Entitled *The New Chemistry*, it was similar in tone to Hofmann's earlier volume in its insistence that a fundamental change had taken place in chemistry in recent years - a change which Cooke characterized as having "the great law of Avogadro" at its base and the doctrine of valence as "its most distinctive feature".

In this work Cooke again introduced the crith and clearly developed the implied relation between the "Volumgewichte" or specific gravity of a gas in criths and its molecular weight (p. 71):

> ... represent by n the constant number of molecules, some billion billions, which a litre of each and every gas contains, when under standard conditions of temperature and pressure. Then the weight of each molecule of hydrogen will be 1/n of a crith, and that of each molecule of oxygen 16/n of a crith, and evidently, 1/n:16/n = 1:16. That is, again, the weights of the molecules have the same relation to each other as the weights of the equal gas-volumes.

Cooke then proceeded to remove the troublesome factor of two and to introduce the microcrith (pp. 72-73):

> Unfortunately, however, for the simplicity of our system, but for reasons which will soon appear, it has been decided to adopt as our unit of molecular weight not a whole hydrogen molecule [as numerically implied by the crith scale] but the half molecule ... In order to give a still greater definiteness to our conceptions, I propose to call the unit of molecular weight we have adopted a *microcrith*,

even at the risk of coining a new word. We have already become familiar with the crith, the weight of one litre of hydrogen, and I will now ask you to accept another unit of weight, the half-hydrogen molecule, which we will call for the future a microcrith. Although a unit of a very different order of magnitude, as its name implies, the microcrith is just as real a weight as the crith or the gramme.

In other words, Cooke had introduced an atomic mass unit based on the standard H = 1.

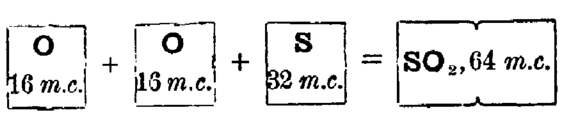
Indeed, later in the book, he even went so far as to approximate the conversion factor between the crith and microcrith and, by implication, between the microcrith and the gram (p. 75):

According to Thompson, one cubic inch of any perfect gas contains, under standard conditions, 10^{23} molecules. Hence, one litre contains 61×10^{23} molecules and 1 crith = 122×10^{23} microcriths.

Comparing for effect this number with the estimated mass of the earth, Cooke admitted that "the limit of error" was larger but felt certain that "this difference is one which future investigation will in all probability remove".

From Cooke's *New Chemistry* both the crith and the microcrith (now abbreviated as m.c.) proceeded to make their way into a number of high school chemistry texts published in the 1880's and 1890's, including those by Youmans (1881) (10), Avery (1881) (11), Clarke (1884) (12), and Williams (1896, 1897) (13,14). In fact, Avery even went so far as to include both composition diagrams and a table of atomic weights explicitly labeled in units of microcriths. Interestingly, however, the author has never encountered either a foreign or a college-level chemistry textbook which made reference to the microcrith, though, as mentioned earlier, several did make use of the crith, and by 1900 most of the later editions of the above texts had deleted all references to both units (15). Why was the microcrith confined largely to American high school chemistry texts and what accounts for its decline by the turn of the century?

There are a number of plausible answers to both of these questions. Cooke was extremely influential in shaping the content of the high school chemistry course in the United States in the last quarter of the 19th century. His *New Chemistry* was a popular exposition of recent advances in chemical theory which served as an easily accessible reference for high school authors seeking to update their introductory textbooks - many



A microcrith composition diagram from Avery's 1881 text (11)

Name.	*Symbol.*	*Microcriths.*	*Name.*	*Symbol.*	*Microcriths.*
Aluminum	Al	27.3	Gold (*aurum*)	Au	196.2
Antimony (*stibium*)	Sb	122	Hydrogen	H	1
Arsenic	As	74.9	*Indium*	In	113.4
Barium	Ba	136.8	Iodine	I	126.53
Beryllium (*See Glucinum.*)	Be		*Iridium*	Ir	192.7
Bismuth	Bi	210	Iron	Fe	55.9
Boron	B	11	*Lanthanum*	La	139
Bromine	Br	79.75	Lead (*plumbum*)	Pb	206.4
Cadmium	Cd	111.6	*Lithium*	Li	7.01
Cæsium	Cs	132.5	Magnesium	Mg	23.98
Calcium	Ca	39.9	Manganese	Mn	54.8
Carbon	C	11.97	Mercury (*hydrargyrum*)	Hg	199.8
Cerium	Ce	141.2	*Molybdenum*	Mo	95.8
Chlorine	Cl	35.37	Nickel	Ni	58.6
Chromium	Cr	52.4	*Niobium* (*See Columbium*).	Nb	
Cobalt	Co	58.6	Nitrogen	N	14.01
Columbium	Cb	94	*Norwegium*	No	72.
Copper (*cuprum*)	Cu	63.1	*Osmium*	Os	198.6
Davyum	Da	153	Oxygen	O	15.96
Decipium	De	157	*Palladium*	Pd	106.2
Didymium	Di	147	Phosphorus	P	30.96
Erbium	Er	169	Platinum	Pt	196.7
Fluorine	F	19.1	Potassium (*kalium*)	K	39.04
Gallium	Ga	69.8	*Rhodium*	Rh	104.1
Germanium			*Rubidium*	Rb	85.2
Glucinium (*See Glucinum*).			*Ruthenium*	Ru	103.5
Glucinum	Gl	92	*Selenium*	Se	79
			Silicium (*See Silicon.*)	Si	

Part of an atomic weight table in microcrith units from Avery's 1881 text (11)

of whom lacked professional training as chemists. Even more importantly, Cooke had issued an influential pamphlet outlining his (and, by implication, Harvard's) conception of the minimum requirements for an acceptable high school laboratory course in chemistry (16). "The Pamphlet", as it came to be called, was widely known among high school teachers during the last quarter of the 19th century and it is only natural that the teachers also paid attention to Cooke's other chemical writings - an obligation not felt by chemists at the college level or in other countries.

By 1900, however, Cooke's influence was on the decline. In addition, the establishment of the first International Committee on Atomic Weights the same year led to an official adoption of an atomic weight scale based on the O = 16 standard rather than the H = 1 standard, which was the basis of the microcrith unit. Although the H = 1 scale was (and still is) pedagogically attractive and the burst of enthusiasm for gas density measurements in the 1860's had focused attention on the volatile hydrides used to such good advantage by Hofmann in his book, the fact remained that oxygen formed a much greater range of stable compounds. Consequently, as Berzelius had argued many years earlier, much more accurate atomic weights could be derived from the use of an oxyen standard and the direct gravimetric analyses of oxides. The limited number of known hydrides, on the other hand, prevented such a direct comparison for the H standard and the use of oxides with this standard required an indirect calculation, whose accuracy was, in turn, limited by the accuracy of the known H:O value derived from the analysis of water (17). And so the crith and microcrith faded from memory and the situation stabilized until the discovery of isotopes, the development of accurate mass spectrometers and the coming of the ^{12}C scale and the unified atomic mass unit.

References and Notes

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17. See the interesting discussion in J. W. Mellor, *Modern Inorganic Chemistry*, Longmans, Green & Co., London, 1927, pp. 81-82.

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CHEMICAL ARTIFACTS

The Chandler Chemical Museum

Leonard Fine, Columbia University

The Chandler Chemical Museum is a unique record of many aspects of the history of American chemistry. As the last and largest of the great 18th and 19th century "philosophical cabinets," it is a collection of unparalleled significance for understanding changing patterns of chemical pedagogy. As a diverse selection of chemical artifacts, it is a rich resource for students of the history of chemical technology. And as a legacy of Charles Frederick Chandler's multifaceted contributions to chemistry and commerce, dating from the founding of the Columbia School of Mines in 1866, it is an important element of the history of Columbia University, of the City of New York, and of the Chemist's Club and the

Charles Frederick Chandler