DENISON-HACKH STRUCTURE SYMBOLS: A FORGOTTEN EPISODE IN THE TEACHING OF ORGANIC CHEMISTRY

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Introduction

The history of chemical nomenclature and symbolism is resplendent not only with proposals that were once widely used in the chemical literature, but which have since been displaced by more modern developments, but also with those which, however logical, were doomed to oblivion almost from their inception and which now survive as historical relics to be found only in the papers and books of their originators (1). Some of these latter proposals (Fig. 1) (2), such as the geometric symbolism of Hassenfratz and Adet, which was designed to encode the nomenclature reforms of Lavoisier and his collaborators, or the circle symbols of Dalton and Loschmidt, have at least managed, despite having never been widely adopted, to make it into the history books, whereas others remain forgotten in the dusty back issues of unread journals (3). This latter scenario was unfortunately the fate of the Denison-Hackh proposals for organic symbolism, despite the fact that certain aspects of these symbols have since been independently rediscovered and are currently widely used in the chemical literature. It is this latter irony which provides both a philosophical and a sociological justification for indulging in a brief historical retrospect of this forgotten symbolism.

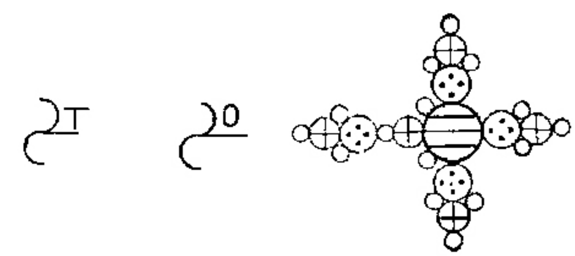

__Figure 1__. Chemical symbols which have made the history books despite never having been widely adopted by chemists. (Left): Hassenfratz and Adet symbols for tartaric and oxalic acid; (Right): Dalton's circle symbolism for alum.

Denison-Hackh Structure Symbols

In the October 4, 1918 issue of *Science*, Mr. Ingo W. D. Hackh, an assistant in the Department of Chemistry at the University of California-Berkeley, published a short article entitled "Organic Symbols," in which he proposed replacing the conventional structural formulas of organic chemistry with pure topological bonding or framework formulas in which the conventional letter symbols of Berzelius for H, O, N and C were eliminated and replaced instead by bond nodes corresponding to their common valence connectivities of one, two, three and four, respectively (Fig. 2) (4). Only when less common elements, such as S, P, or the halogens, were present in an organic compound was it necessary to explicitly use the corresponding letter symbols. Just as a single bond was a straight line, so a double bond was represented as a loop and a triple bond as a circle with a line through the center (Fig. 3). When these proposals were consistently followed, the result, according to Hackh, was a unique and distinctive "structure symbol" for each of the more than 100,000 organic compounds known at the time (Fig. 4)—a symbol that was both compact and easy to write and that, as an additional bonus, also facilitated the taking of lecture notes.

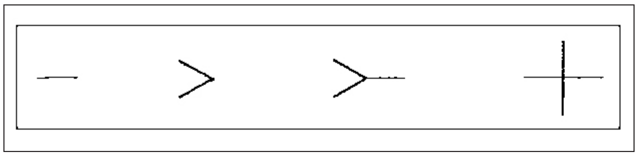

Figure 2. *(Left to Right): Bond nodes for hydrogen, oxygen, nitrogen, and carbon.*

The brief article in *Science* was not Hackh's first attempt at publicizing his symbolism, as he had already published a short paper on this subject in the spring of 1918 in the soon to be defunct *Canadian Chemical Journal* (5). Nor was this symbolism completely original with Hackh, since he also acknowledged having gotten the basic idea from a suggestion published by a certain Dr. Henry S. Denison in *The Denver Medical Times* four years earlier (6). But what had been merely a passing interest for Denison soon became an abiding obsession for Hackh, who would continue to refine and apply the symbols over the next two decades in a variety of papers and books (7-24).

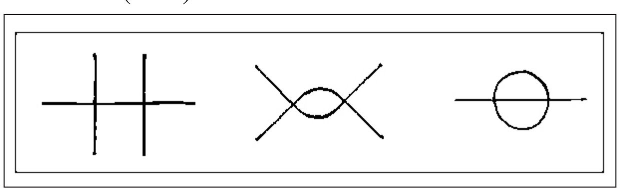

Figure 3. *Structure symbols for single, double, and triple bonds. (Left to Right): ethane, ethene, and ethyne.*

The end product of this refinement process was described in a paper published in the *Journal of Chemical Education* in 1930 (21) and in a small booklet for students and teachers published the next year under the title *Structure Symbols for Organic Chemistry* (24). This consisted of 38 pages of text followed by 29 hand drawn plates giving the structure symbols for over 1,000 organic compounds. These two publications reveal refinements designed to indicate both the presence of chiral carbon centers (Fig. 5) and, if desired, the presence of various bonding and nonbonding electron pairs (Fig. 6). But perhaps the best known and most influential of Hackh's various publications was the highly illustrated *Dictionary of Chemistry*, which he produced for the Blakiston Company of Philadelphia in 1929 and which he soon filled with many examples of his structure symbols (20).

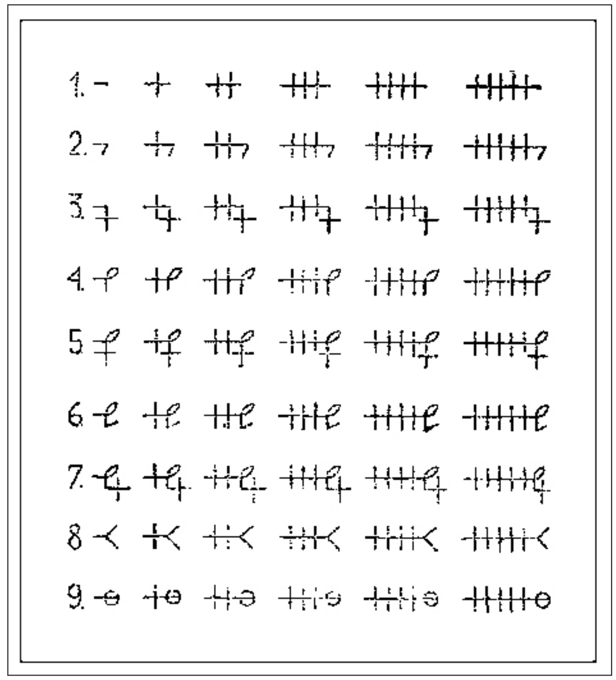

Figure 4. *Structure symbols for various homologous series: 1) alkanes, 2) alcohols, 3) methyl ethers, 4) aldehydes, 5) methyl ketones, 6) carboxylic acids, 7) methyl esters, 8) primary amines, 9) nitriles.*

Failure

So how successful was Hackh in convincing his fellow chemists of the merits of his new "structure symbols," as he came to call them? The answer, as far as I can determine, is that his efforts ended in failure. Though J. J. Sudborough, the British translator of the popular organic textbook by the German chemist, August Bernthsen, noted Hackh's 1918 article in Science and incorporated a brief mention of the symbolism in the 1922 and subsequent editions of the text (25), Hackh's efforts to interest American chemical educators were largely unsuccessful. Over the years, his 1930 article in the Journal of Chemical Education elicited a single reader response, which largely dealt with the reader's own eccentric proposals for a "chemical shorthand" (26); and a review of Hackh's subsequent booklet in the same journal by C. A. Buehler of the University of Tennessee-Knoxville provided only a lukewarm endorsement (27):

> The present structural formula seems so well established that it is not likely to be replaced unless a much more desirable method of representation is devised. Any such method will have to overcome custom, and to do this its advantages must outweigh decidedly its disadvantages. The structure symbol does have the advantage of compactness and simplicity, but is that

> sufficient to overcome the inconvenience of having the chemical symbols omitted? Is it not desirable to make our representations intelligible to, at least, the scientifically interested public? Taking everything into consideration, the reviewer does not feel that the structure symbol is an improvement over the structural formula.

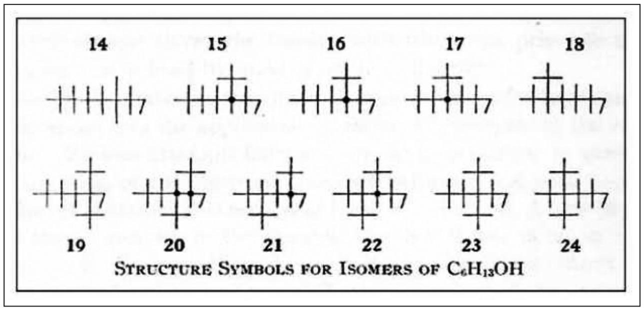

Figure 5. *Hackh's method of indicating chiral carbon centers (black dots) illustrated using the various isomers of hexanol.*

L. I. Smith, who reviewed the booklet for the *Journal of Physical Chemistry*, was even more harsh in his assessment of the possible uses of the symbols in undergraduate teaching (28):

> As a teaching device, the reviewer doubts very much if these symbols would have the value claimed for them, namely, that they make it possible to include a larger amount of organic chemistry in the usual courses; and it would appear that the new symbols might have the definite disadvantage of getting the student even further away from reality than the usual structural formulas do, since in the new symbols no symbols for carbon, hydrogen, nitrogen, or oxygen appear.

However, this criticism was offset by Smith's enthusiastic endorsement of the symbolism for advanced students and research workers (28):

> But as a tool for advanced students and research workers, these new symbols appear highly advantageous, for they amount to a shorthand way of representing the structural formulas and can be written in much less time than even the most abbreviated structural formulas. This, it seems to the reviewer, is the field in which these symbols have their greatest advantage, and this advantage is a considerable one.

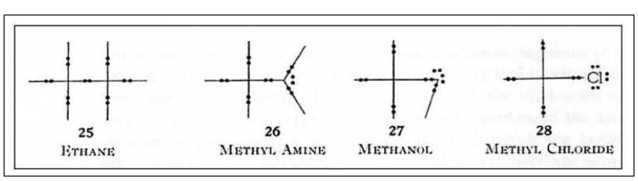

Figure 6. *Structure symbols with bonding and nonbonding electron pairs superimposed.*

Likewise, though Hackh's chemical dictionary would go through many subsequent editions—some as late as the 1980s—Julius Grant, who took over editorship of the dictionary after Hackh's death in 1938, began to eliminate progressively most of the references to Hackh's structure symbols, starting with the 3rd edition of 1944 (29).

Some Historical Ironies

By the late 1940s it is safe to say that essentially all traces of Hackh's original proposals had disappeared from the chemical literature, though ironically the following decades would see several independent applications of their underlying premises, albeit without any mention of Hackh or his original proposals. The first of these occurred in the late 1950s and early 1960s with the rise of framework molecular models (30), the most popular of which were the versions devised by Fieser (31) and by Prentice-Hall (32) for the use of students taking sophomore organic chemistry, both of which were, in turn, based on the more expensive precision metal Dreiding models used by research chemists (33).

These framework models were literally 3D versions of Hackh's 2D structure symbols, though their application in teaching organic chemistry during these decades was never coupled, to the best of my knowledge, to proposals, similar to those of Hackh, for drawing 2D topological projections of the resulting 3D models. Indeed, this development was doubly ironic since, 22 years before these developments, Hackh himself had constructed a series of 3D framework models from heavy gauge wire that were identical in appearance to the much later plastic FMM Prentice-Hall models (Fig. 7) and had explicitly noted that his structural symbols were nothing more than 2D topological bonding maps or "graphs" of these models.

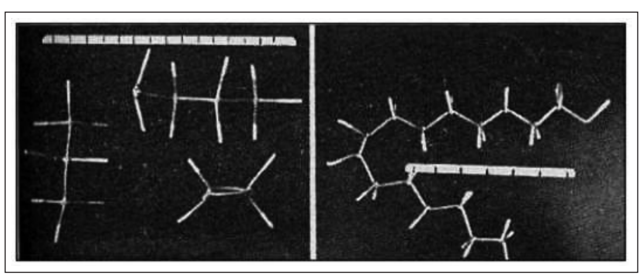

Figure 7. *Wire framework molecular models introduced by Hachk in the second edition (1937) of his chemical dictionary more than two decades before they came into common use by students and research workers in the field of organic chemistry.*

A second irony occurred in 1970, when an article was published by G. W. Evans in *Chemistry*—the ACS sponsored publication designed for high school chemistry teachers—entitled "A Proposed Structural Shorthand for Organic Chemistry," in which Hackh's structural symbols were once again described but represented as an original suggestion on the part of the author and without any reference to Hackh whatsoever (34). This oversight was caught by readers of the journal, and a few months later Evans published a letter properly crediting Hackh but claiming to have had no prior knowledge of his work (35).

Yet a third and final irony lies in the fact that, since the 1970s, a type of highly abbreviated organic structural symbolism closely related to Hackh's original proposals, but even more minimalist in content, has come into general use in the chemical literature (Fig. 8). Already in the late 19th century it was commonplace to represent the benzene ring as an abstract hexagon in which not only the C and H atoms were implicit but the C–H bonds as well. In the case of substituted benzene compounds only the functional groups and nonhydrogenic substituents were explicitly indicated with atomic symbols. By the early 20th century this type of abbreviated symbolism was also being extended to other ring systems, including polycycles, such as naphthalene and anthracene, and heterocycles, such as pyridine and dioxane; and by mid-century its was being widely used in the literature dealing with natural products and biochemistry. The final stage in the evolution of this symbolism—its logical extension to chain hydrocarbons and their derivatives—appears, for reasons which will be discussed in a later section, to have been largely stimulated by the development of explicit retrosynthetic strategies for the synthesis of complex natural products in the late 1960s (36).

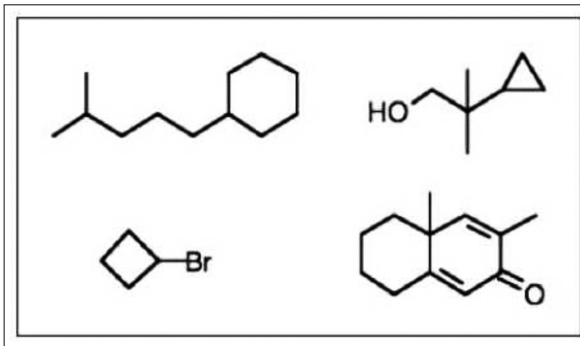

Figure 8. *Examples of modern skeletal structure symbols.*

While similar in spirit to Hackh's original proposals, there are, of course, some important differences between Hackh's symbols and modern skeletal formulas. Whereas all bonds are explicitly articulated in Hackh's symbols, C–H bonds and bonds within functional groups are often left implicit in the modern symbolism. Whereas the symbols for H, O, N, and C are implicit in Hackh's symbolism, only the symbols for H and C are implicit in the modern symbolism and then only if they are not part of a functional group. In keeping with their purely topological significance, carbon chains were written in a straight line or as branched at right angles in Hackh's symbols, whereas they are written in a zigzag fashion in modern symbolism, since suppression of the C–H bonds now requires the presence of kinks in the chain to indicate the locations of secondary carbon centers. Likewise, terminal points now indicate the locations of primary carbon centers rather than hydrogen atoms, and the convergence of three bonds at a common junction now indicates the location of a tertiary carbon center rather than a nitrogen atom.

Who was Ingo Hackh?

Before speculating on the reasons for Hackh's failure to win widespread support for his symbolism, it is necessary to say a little about his life and career, since both are relevant to our final conclusions. Born Ingo Waldemar Dagobert Hackh (Fig. 9 and 10) in Stuttgart, Germany, on March 25, 1890, Hackh received a Ph.G. degree at

Figure 9. *A young 29-year old Ingo Hackh around the time he first proposed his system of structure symbols as he appeared in the 1919 issue of* Chips, *the student yearbook for the College of Physicians and Surgeons in San Francisco. (Courtesy of the Institute of Dental History and Craniofacial Study, University of the Pacific.)*

age 19 from the Technische Universität Braunschweig. For readers unfamiliar with this degree, it stands for pharmacy (Ph) graduate (G) and was generally awarded for having completed a two- or three-year undergraduate program of course work. Graduation was followed by employment as a chemist for the firm of E. DeHaen in Seelze, Germany, and immigration to the United States in July of 1912. From 1912 to 1915 Hackh was employed as a pharmaceutical chemist, first by the Abbott Alkaloid Company of Chicago and San Francisco (now Abbott Laboratories) and then by the Von Ruck Research Laboratories. In 1915 he entered the chemistry program at the University of California, Berkeley, from which he received an A.B. degree in chemistry in 1917. Staying on for another year at Berkeley as an assistant in the Chemistry Department, Hackh was appointed in late 1918, at age 28, as Professor of Biochemistry at the College of Physicians and Surgeons in San Francisco, a position he held until his premature death in 1938 at age 48.

***Figure 10**. Hackh as he appeared in 1929 at age 39, the year the first edition of his chemical dictionary was published. (Courtesy of the Institute of Dental History and Craniofacial Study, University of the Pacific.)*

In addition to his short booklet on organic symbolism, his highly successful chemical dictionary, and over two dozen published papers in a wide variety of chemical and pharmaceutical journals, Hackh also published a speculative monograph in German on atomic structure and the periodic table titled *Das synthetisches System der Atom* (1914), a popular account of the discovery of the chemical elements titled *The Romance of the Chemical Elements: Their History and Etymology* (1918), and a second short study booklet for students titled *Chemical Reactions and their Equations: A Guide for Students of Chemistry* (1928) (37-40). Though initially favoring a spiral form of the periodic table in his 1914 monograph, Hackh later opted for a rather eclectic rectangular table, which he advocated in numerous published papers and also incorporated into his later books and dictionary (41-42). Unlike his structure symbols, his proposals concerning the periodic table are still mentioned in most histories of the subject and on the websites of those who are currently obsessed with this topic (43-44).

Why was Hackh Unsuccessful?

The answer to this question will come in two stages—the first sociological in nature and the second scientific. Though most scientists wish to deny it, repeated studies by sociologists of science have convincingly shown that the ability of a scientist to successfully market his or her scientific ideas depends as much on their personal prestige within the scientific community as on the intrinsic merits of their ideas (45). Hackh not only lacked such prestige within the chemical community—having come out of a pharmacy background and having spent most of his career teaching organic chemistry and biochemistry to students of dentistry; he actually operated at the fringes of the chemical community. This fringe status was also reflected in the fact that all of his books were published by the Blakiston Company of Philadelphia, a publisher that specialized in textbooks and monographs targeted at medical, pharmacy, and dentistry schools rather than at university chemistry departments.

Despite his obvious competence, Hackh was not a practicing research organic chemist in the laboratory sense, and he appears to have had no contact with those at the center of the organic chemistry research community. Unfortunately, his attempts to circumvent this problem by publishing in the chemical education literature overlooked a depressing truth about curriculum innovation: namely, that significant changes in subject content, notation, and symbolism essentially occur by a one-way process which flows from the research literature into the chemical education literature but almost never in the reverse direction. In other words, innovations prompted by pedagogical considerations, however cogent, almost never have a significant impact on the research literature.

This latter truth is illustrated by the fact, mentioned earlier, that the minimalist, skeletal, organic symbolism used today, not only in the research literature but, to an increasing extent, in the textbook literature, appears to have originated in the research literature dealing with the chemistry of complex natural products rather than in an explicit attempt to streamline the teaching of organic chemistry. As the natural products being studied became increasingly complex and the required synthetic routes ever more lengthy and challenging, there was increasing pressure to move beyond the personal intuition or *chemisches Gefühl* approach of earlier workers in the field to an explicit articulation of the assumptions underlying the various synthetic strategies. The resulting "retrosynthesis" methodology soon came to focus on two key issues: techniques for the manipulation of the underlying carbon framework (e.g., extension, ring formation, stereospecificity, etc.) and techniques for the insertion, exploitation, and/or masking of key functional groups—the two essential features of an organic structure that are retained in our modern minimalist, skeletal formulas.

This then provides us with the scientific reasons for Hackh's ultimate failure. His own structure symbols failed to properly identify and focus on these two essential parameters of modern synthetic organic chemistry. By retaining the H–C bonds, his symbols became too cluttered and confusing when applied to very complex structures. By selectively treating those functionalities containing oxygen and nitrogen in the same manner as the carbon framework, he failed to properly highlight what was in fact the most important determinant of reactivity for most organic compounds. In short, his symbols, however internally logical and self-consistent, both failed to make explicit those features (i.e., certain functional groups) which should have been emphasized and to make implicit those (i.e., the C–H bonds) which could be safely deemphasized.

Figure 11. *Two late 18th-century pharmacy jars illustrating traditional pharmaceutical symbolism.*

In closing, I cannot resist making one final speculative observation. In reading Hackh's various publications on this subject, I was struck by an increasing tendency on his part to make the resulting formulas evermore stylized and abstract in appearance, so that in the end they look almost like mystical symbols or hieroglyphs, as well as by his repeated attempts to eliminate as many explicit atomic symbols and other letter abbreviations (such as R for generalized alkyl groups) as possible, as though they were so many would-be blemishes on the geometric purity of the final symbols. Given Hackh's European pharmacy background, in which abstract symbolism was once a commonplace in the labeling of pharmacy bottles (Fig. 11), I cannot help but wonder whether a knowledge of this ancient pharmaceutical tradition might have played a subconscious role in shaping these two tendencies (46).

ACKNOWLEDGMENTS

I would like to thank Dr. Dorothy Dechant, Museum Curator of the Institute of Dental History and Craniofacial Study, University of the Pacific, for her assistance in providing portraits of Hackh (Fig. 9 and 10) and for her help in verifying certain biographical details. Thanks also to Dr. Theodor Benfey, former editor of *Chemistry*, for his help with regard to the Evans affair.

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