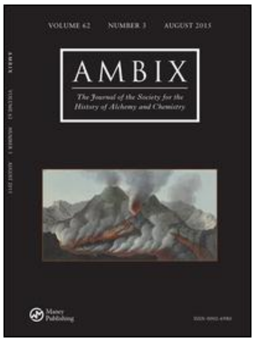

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"Just as the Structural Formula Does": Names, Diagrams, and the Structure of Organic Chemistry at the 1892 Geneva Nomenclature Congress*

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At the Geneva Nomenclature Congress of 1892, some of the foremost organic chemists of the late nineteenth century crafted a novel relationship between chemical substances, chemical diagrams, and chemical names that has shaped practices of chemical representation ever since. During the 1880s, the French chemist Charles Friedel organised the nomenclature reform effort that culminated in the Geneva Congress; in the disorderly nomenclature of German synthetic chemistry, Friedel saw an opportunity to advance French national interests and his own pedagogical goals. Friedel and a group of close colleagues reconceived nomenclature as a unified field, in which all chemical names ought to relate clearly to one another and to the structure of the compounds they represented. The German chemist Adolf von Baeyer went a step farther, arguing for names that precisely and uniquely corresponded to the structural formula of each compound, tailored for use in chemical dictionaries and handbooks. Baeyer's vision prevailed at the Geneva Congress, which consequently codified rules for rigorously mapping structural formulas into names, resulting in names that faithfully represented the features of these diagrams but not always the chemical behaviour of the compounds themselves. This approach ultimately limited both the number of chemical compounds that the Geneva rules were able to encompass and the breadth of their application. However, the relationship between diagram and name established at the Geneva Congress became the foundation not only of subsequent systems of chemical nomenclature but of methods of organising information that have supported the modern chemical sciences.

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On the evening of Easter Monday, 18 April 1892, thirty-four chemists assembled in the Hôtel de la Métropole, at the southwestern tip of Lake Geneva where it empties into the Rhône, looking out over the Jet d'Eau and across the lake to the mountains to the north. The group included presidents of national chemical societies, editors of prestigious journals, and three future Nobel laureates, gathered for an event that a local newspaper promised would "mark an important date in the history of chemistry."[1] They had come to Geneva to address a serious obstacle to the continued progress of chemical science and industry: confusing nomenclature. Over the following four days—cold, but pleasant, the Congress secretary noted in his diary—in morning and afternoon sessions of about three hours each, the delegates of the Geneva Congress traversed the field of organic chemical substances and mapped it out in names.[2]

What's in a nomenclature? In the case of organic chemistry, the answer is both complex and simple. The substance of organic chemical nomenclature is complex: thousands of pages of byzantine rules for generating millions of names, most of which sprawl out illegibly over dozens of syllables.[3] Underlying this complexity, however, is a simple principle: the systematic name of a compound should express its chemical structure (Figure 1).

More specifically, systematic chemical names are one-to-one mappings of structural formulas, diagrams prized by chemists as their "graphic language" for representing chemical substances as networks of atoms linked by bonds.[4] Systematic nomenclature is a compromise: chemists accept ungainly chemical names and obscure nomenclature rules as a "necessary evil" that makes it possible to identify and order chemical substances according to the much-loved structural formulas.[5]

This relationship between name, diagram, and substance was established at the Geneva Congress.[6] The sixty-two rules codified there were to be the foundation of a general method for the "faithful translation" of structural formulas into names. The Geneva rules christened only a small fraction of then-known organic compounds with systematic names, and awkward names, at that; after an initial burst of enthusiasm, most chemists saw them as excessively rigid and narrow in scope. Nevertheless, contemporary methods of organic chemical nomenclature

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[1] "Chronique Locale. Congrès de Chimie," *Journal de Genève*, 17 April 1892, 2.

[2] Amé Pictet, Agenda, entries of 19–21 April 1892, Musée d'Histoire des sciences, Geneva, Z 306.

[3] See, for example, Henri A. Favre and Warren H. Powell, eds., *Nomenclature of Organic Chemistry: IUPAC Recommendations and Preferred Names 2013* (Cambridge: Royal Society of Chemistry, 2014) (1,568 pp.); Chemical Abstracts Service, *Chemical Substance Name Selection Manual*, 2 vols. (Washington, D.C.: Chemical Abstracts Service, 1982) (approx. 2,000 pp.).

[4] Roald Hoffmann and Pierre Laszlo, "Representation in Chemistry [1991]," in *Roald Hoffmann on the Philosophy, Art, and Science of Chemistry*, ed. Jeffrey Kovac and Michael Weisberg (New York: Oxford University Press, 2012), 179.

[5] Kurt L. Loening, foreword to Pieter Eduard Verkade, *A History of the Nomenclature of Organic Chemistry*, trans. S. G. Davies, (Boston: Reidel, 1985), ix.

[6] I refer to structural formulas as "diagrams" in order to highlight their *visual* mode of representing facts or claims about chemical constitution, which the chemists who are the subject of this essay sought to express using words. I make no claim here regarding the relationship between other sorts of visual representation and "these little diagrams," as Hoffmann and Laszlo call them; "Representation in Chemistry," 164.

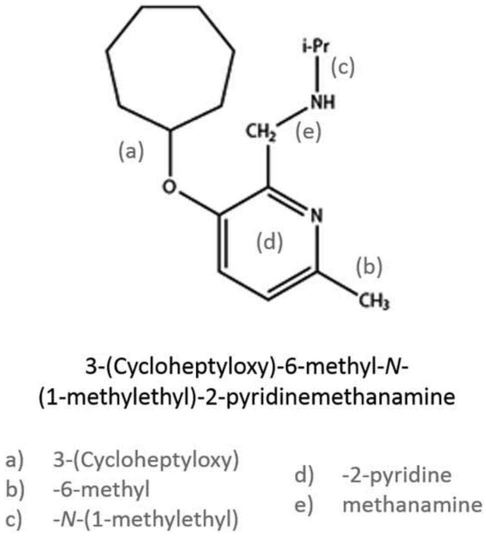

FIGURE 1 The structural formula and systematic name of the seventy-five millionth small molecule added to the Chemical Abstracts Service Registry. "CAS REGISTRY Surpasses 75 Million Small Molecules," Press Release of 11 November 2013, http://www.cas.org/news/media-releases/75-millionth-substance.

have their roots in the principles that the Geneva delegates formulated and followed in establishing these rules.[7]

The significance of the Geneva Congress lay not in a set of chemical names, but in a conception of chemical nomenclature. As the pace of organic synthesis accelerated during the 1870s and 80s, conflicting methods for naming organic compounds emerged. New synthetic organic substances—some, such as the azo compounds, prized as potential dyes or pharmaceuticals—accumulated multiple different names, and these chemical synonyms became an impediment to chemists seeking to keep track of their rapidly developing field.[8] However, many of these names shared a common basis: the arrangement of chemical subunits that made up the compound, as understood according to the principles of structure theory. Synonymy

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[7] P. E. Verkade, longtime chairman of the IUPAC commission on organic nomenclature, presents a detailed technical analysis of both the limitations and influence of the Geneva nomenclature in his account of the Congress, by far the most thorough historical treatment of its intellectual subject matter: Verkade, *A History*, 1–48, 276–98. Other works that discuss the Geneva Congress in surveying the development of chemical nomenclature during the nineteenth and twentieth centuries include Maurice P. Crosland, *Historical Studies in the Language of Chemistry* (New York: Dover, 1978), 347–54; Bernadette Bensaude-Vincent, "Languages in Chemistry," in *The Cambridge History of Science. Volume 5: The Modern Physical and Mathematical Sciences*, ed. Mary Jo Nye (Cambridge: Cambridge University Press, 2003), 174–90; James G. Traynham, "Organic Nomenclature: The Geneva Conference 1892 and the Following Fifty Years," in *Organic Chemistry: Its Language and Its State of the Art*, ed. M. Volkan Kısakürek (New York: VCH, 1993), 1–8; James G. Traynham, "The Familiar and the Systematic: A Century of Contention in Organic Chemical Nomenclature," in *Essays on the History of Organic Chemistry*, ed. James G. Traynham (Baton Rouge: Louisiana State University Press, 1987), 114–26; Victor Grignard, *Traité de Chimie Organique* (Paris: Masson, 1935), vol. 1, 1073–108.

[8] I use "synonym" here and throughout this essay in its taxonomic sense, that is, to refer to one of multiple different terms that specifically refer to the same object. This is the sense in which the participants in the Geneva Congress used the term, e.g. in a discussion of how best to avoid the problem of the "multiplicity of synonyms"; "Rapport de la Sous-Commission," *Association Française pour l'Avancement des Sciences: Compte Rendu* 21 (1892): 394.

made nomenclature reform desirable; the chemical industry made it valuable; structure theory made it conceivable.

None of these, however, made it happen. That was the work of Charles Friedel. While his German peers put structural formulas to use in their race to outdo each other's synthetic achievements, the Alsatian savant battled opponents in the Parisian academic bureaucracy over the legitimacy of structure theory and its place in French classrooms. In this context, Friedel and his scientific allies reconceived nomenclature not simply as a collection of names but as a field that spanned all organic substances and that might be made to express experimentally attested structural relationships between them. They saw an international effort to bring about such a system of nomenclature as an opportunity to advance French chemistry and their own position within it.

The reform that the Geneva Congress undertook, however, would be guided by a different vision of how, and where, chemical names might be put to work. German chemist Adolf von Baeyer convinced his fellow delegates that their nomenclature should comprise a set of rules for generating unique, "official" names tailored for use in indexing chemical journals and reference works. In carrying out this plan, the Geneva Congress invented the sort of name, and articulated the relationship between name, diagram, and substance, that has distinguished chemical nomenclature ever since.

The relationship between chemical diagrams and chemical substances has justly received the careful attention of historians and philosophers. These scholars have illuminated the manipulability, visual suggestiveness, and semantic density that have made graphical representations such fruitful "paper tools" for organic chemists over the past two centuries.[9] Chemical nomenclature since Lavoisier, in contrast, has received comparatively little recent scholarly attention, as Bernadette Bensaude-Vincent has noted.[10] For historians as for chemists, rules of organic chemical nomenclature can be technical, tedious, and seemingly far removed from the epistemic shifts, instrumental revolutions, and transformations of the material world that have characterised the modern chemical sciences. Yet the tedium and technicality of systematic names have been the price that chemists have paid to maintain the utility of their favourite diagrams and the cumulative development of their science. Neither of the latter can be fully understood apart from the former, and their relationship was forged at the Geneva Congress.[11]

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[9] Ursula Klein, *Experiments, Models, Paper Tools: Cultures of Organic Chemistry in the Nineteenth Century* (Stanford: Stanford University Press, 2003); Mary Jo Nye, *From Chemical Philosophy to Theoretical Chemistry: Dynamics of Matter and Dynamics of Disciplines, 1800–1950* (Berkeley, CA: University of California Press, 1993), 73–102, 196–223; Alan J. Rocke, *Image and Reality: Kekulé, Kopp, and the Scientific Imagination* (Chicago: University of Chicago Press, 2010); Leo B. Slater, "Instruments and Rules: R. B. Woodward and the Tools of Twentieth-Century Organic Chemistry," *Studies in History and Philosophy of Science* 33 (2002): 1–33; François Dagognet, *Tableaux et Langages de la Chimie* (Paris: éditions du Seuil, 1969).

[10] Bensaude-Vincent, "Languages in Chemistry," 175. For exceptions, see the works mentioned in note 7, especially Crosland, *Historical Studies* and Verkade, *A History*, as well as Dagognet, *Tableaux et Langages*.

[11] A note on translation: for the sake of intelligibility, I have translated French and German chemical names, affixes, roots and orthography into the corresponding forms used in contemporaneous English. The Geneva Congress

"The language itself must be transformed"

The international collection of chemists who gathered at Geneva was well suited to taking action on matters of organic chemical nomenclature (Figure 2; Table 1). Nearly all were specialists in organic chemistry, and many, including their host, Carl Graebe, had already taken special interest in matters of naming. Baeyer and Friedel, leading figures of the field, had the professional stature to lend authority to the work of the Congress. So did rising stars like Emil Fischer, who took advantage of the convenient timing and location of the Congress to spend a week with his former teacher Baeyer, relaxing and "practicing a little French" in a Swiss resort town before continuing on to Geneva.[12] Ferdinand Tiemann and Maurice Hanriot, editors of the influential journals of the German and French chemical societies, attended; Friedrich Beilstein, compiler of the exhaustive, indispensable *Handbuch der Organischen Chemie*, was unable to make the journey from St Petersburg, but contributed his approbation and several suggestions.[13] Such editors were in a position both to communicate the Congress's decisions on nomenclature to a broad audience and, more importantly, to enforce them in the pages of their publications.[14]

The official proceedings of the Congress—and historical accounts that follow it—describe a shared aim that united this august group in pursuit of nomenclature reform: the desire to bring order to a chemical lexicon set in disarray by the rapid accumulation of new compounds and alternative ways of naming them.[15] However, this common purpose was a product of the reform effort that culminated

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[11] *Continued*
was conducted primarily in French; the official text of its rules was published in French, as well. The Congress left any decisions regarding how to implement its rules in other languages to the individual authors who applied or translated them. Though the delegates to the Geneva Congress did not address the implications of linguistic difference for chemical nomenclature, others did, especially in discussions that addressed spoken chemical names as well as written ones. I address such matters and provide a more detailed account of the emergence and subsequent history of systematic organic chemical nomenclature in my forthcoming dissertation: Evan Hepler-Smith, "Nominally Rational: Systematic Nomenclature and the Structures of Organic Chemistry, 1889–1940."

[12] Fischer to Baeyer, 22 March 1892, Box 36, Emil Fischer Papers, BANC MSS 71/95 z, The Bancroft Library, University of California, Berkeley. The British delegate Henry E. Armstrong noted that some delegates had difficulty expressing or understanding the intricacies of nomenclature questions in French: "The International Conference on Chemical Nomenclature," *Nature* 46 (19 May 1892): 57.

[13] Michael D. Gordin, "Beilstein Unbound: The Pedagogical Unraveling of a Man and His Handbuch," in *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, ed. David Kaiser (Cambridge, MA: MIT Press, 2005), 11–39; Amé Pictet, "Le Congrès International de Genève Pour La Réforme de La Nomenclature Chimique," *Archives des Sciences Physiques et Naturelles* 27 (1892): 500–1.

[14] There had been no such mechanism for the enforcement of the decisions of the Karlsruhe Congress, an 1860 gathering in which 140 chemists—including Baeyer, Friedel, and three other Geneva delegates—had gathered to discuss chemical terminology and notation. Though memorable and indirectly influential, the Congress had little direct effect on chemists' practice. See Charles-Adolphe Wurtz, "Carlsruhe Compte Rendu," *The Question of the Atom: From the Karlsruhe Congress to the First Solvay Conference, 1860–1911*, ed. Mary Jo Nye, trans. John Greenberg and William Clark (Los Angeles: Tomash, 1984), 5–28; Alan J. Rocke, *Nationalizing Science: Adolphe Wurtz and the Battle for French Chemistry* (Cambridge, MA: MIT Press, 2001), 226–33; Bernadette Bensaude-Vincent, "Karlsruhe, Septembre 1860: l'Atome en Congrès," *Relations internationales* 62 (1990): 149–69; Bensaude-Vincent, "Languages in Chemistry."

[15] Pictet, "Congrès International," 485–86. This "lexicon" took material form in organic chemical reference works, e.g. Max Moritz Richter, *Lexikon Der Kohlenstoff-Verbindungen*, 2nd ed., 2 vols. (Hamburg and Leipzig: L. Voss, 1900).

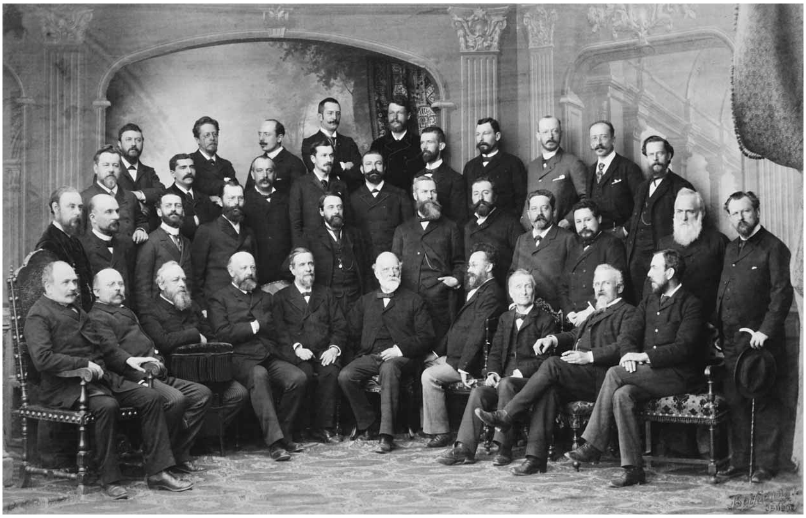

FIGURE 2 The delegates to the Geneva Congress. Deutsches Museum, Munich, Bildstelle, BN 32547, copyright Photo Deutsches Museum. Friedel is in front row centre; Baeyer is two places to the left. For the identities of all of the chemists in this photograph, see Crosland, *Historical Studies*, 351. By kind permission of the Deutsches Museum.

in the Geneva Congress, not its cause. During the 1880s, two sets of chemists each confronted a different problem of chemical language. Chemists studying complex synthetic compounds, predominantly in German settings, were struggling with the various synonyms used by different authors to identify these compounds. In contrast, a faction of Parisian chemists led by Friedel was striving to incorporate terminology and notation at the heart of their approach to chemistry into the highly-regulated French chemical curriculum. Though nomenclature reform brought these two groups together, their goals and perspectives remained distinct.

Both the proliferation of chemical synonyms and Friedel's hopes for pedagogical reform were rooted in the principles of structure theory. Structure theory offered a means of interpreting and predicting chemical phenomena in terms of constitution: the particular patterns in which atoms of elements combined within a molecule. The classification of *in*organic compounds according to their composition had been a central feature of late eighteenth-century chemistry.[16] By the early nineteenth century, however, chemists had found that the composition of organic compounds often did not provide a reliable basis for establishing their identity or relationships. There were even chemical twins, termed *isomers*, which contained the same elements in the same proportions but displayed different chemical properties.[17]

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[16] On the "theory domain of composition" in eighteenth-century chemistry, see Mi Gyung Kim, *Affinity, That Elusive Dream: A Genealogy of the Chemical Revolution* (Cambridge, MA: MIT Press, 2003), 65–110. On "compositionism," see Hasok Chang, *Is Water H_2O: Evidence, Realism and Pluralism* (Dordrecht and New York: Springer Verlag, 2012), 1–70 (defined on 14).

[17] On the emergence of an experimental culture of organic chemistry in the first half of the nineteenth century, see Klein, *Experiments, Models, Paper Tools*, 41–85.

TABLE 1

LIST OF DELEGATES TO THE GENEVA CONGRESS, AFTER THE ROSTER PRINTED IN THE CONGRESS PROCEEDINGS*

Allemagne
MM
A. von Baeyer (Munich)
E. Fischer (Würzburg)
E. von Meyer (Leipzig)
E. Noelting (Mulhous)
F. Tiemann (Berlin)
Angleterre
H.-E. Armstrong (Londres)
J.-H. Gladstone (Londres)
W. Ramsay (Londres)
Autriche
A. Lieben (Vienne)
Z. Skraup (Graz)
Belgique
M. Delacre (Gand)
France
A. Arnaud (Paris)
Ph. Barbier (Lyon)
A. Béhal (Paris)
L. Bouveault (Paris)
P. Cazeneuve (Lyon)
MM
A. Combes (Paris)
C. Friedel (Paris)
A. Haller (Nancy)
M. Hanriot (Paris)
A. Le Bel (Paris)
L. Maquenne (Paris)
Hollande
A.-P.-N. Franchimont (Leyde)
Italie
S. Cannizzaro (Rome)
A. Cossa (Turin)
M. Fileti (Turin)
E. Paterno (Palerme)
Roumanie
C. Istrati (Bucarest)
Suisse
C. Graebe (Genève)
P.-A. Guye (Genève)
A. Hantzsch (Zurich)
D. Monnier (Genève)
R. Nietzki (Bâle)
A. Pictet (Genève)

*Pictet, "Congrès International," 487.

Consequently, Lavoisier's composition-based binomial nomenclature for inorganic compounds could not be applied to organic chemical substances.[18] Names based in a theory of constitution could, but during the 1850s there were many such theories, as the diverse chemical formulas used to express their conclusions illustrated.[19] Some forms of "rational nomenclature" came into use nonetheless, but more often, chemists retained and coined names for organic compounds based on their sources or properties.[20] A substance isolated from ants was

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[18] Crosland, *Historical Studies*, 133–224.

[19] In a textbook fascicle originally published in 1859, August Kekulé dramatized the variety in theories of chemical constitution proposed over the preceding decade with a table of nineteen different formulas for acetic acid (vinegar). August Kekulé, *Lehrbuch der Organischen Chemie* (Erlangen: F. Enke, 1861), 58.

[20] Crosland, *Historical Studies*, 285–318.

"formic acid" (Latin: *formica*); an oil whose vapour caused an acid-soaked splint to burst into bright red flame, "pyrrol" (Greek: *pyrros*, red, fiery + Latin: *oleum*, oil, as in *benzol*); the product of the dehydrogenation of *al*cohol, "aldehyde."[21]

From the late 1850s on, a group of imaginative chemists drew together certain insights from the various constitutional theories of the preceding decade, forming the productive and ever more broadly shared principles of structure theory.[22] These included *atomism*, the assumption that substances were made up of chemically indivisible atoms whose relative weights could be derived by means of certain physical measurements and laws; *substitution*, which divided each molecule into a core subunit belonging to its "parent compound" and one or more "substituents" in place of hydrogen atoms of that parent; *valence*, the concept that atoms of each element formed a characteristic number of bonds to other atoms; the *tetravalence of carbon*, the rule that each carbon atom formed four bonds; and *self-linking*, the ability of atoms of the same element—especially carbon—to bond to one another.

As with previous approaches to constitution, descriptions and classifications based in structure theory could be expressed by conventions of rational nomenclature. August Wilhelm Hofmann fused older applications of prefixes and suffixes into such a scheme of hydrocarbon nomenclature, one of a few naming conventions that gained wide, though selective and informal, adoption. However, a new kind of chemical formula proved more influential.

During the early 1860s, Scottish chemist Alexander Crum Brown developed a style of graphic notation that expressed the constitution of compounds in accordance with the principles of structure theory.[23] Crum Brown's graphical formulas —soon thereafter termed "structural formulas"—represented atoms with element symbols like C, H, and O, and chemical associations between them with lines. Whereas most existing formulas privileged one feature of a compound, structural formulas provided a highly legible basis for identifying the various constitutional units that characterised organic substances and their relationships. By the end of the 1860s, Crum Brown's formulas were in broad use, helping to abate the preceding confusion over notation (Figure 3). Most users of structural formulas insisted that the diagrams were not meant to represent the physical microstructure of compounds, but they sometimes thought about chemical phenomena as if the formulas did.[24] As a shared, visually suggestive means of representing compounds in the

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[21] W. E. Flood, *The Origins of Chemical Names* (London: Oldbourne, 1963), 29–30, 95, 187.

[22] Alan J. Rocke has chronicled this history in illuminating detail. On priority claims regarding structure theory, see Alan J. Rocke, "Kekulé, Butlerov, and the Historiography of the Theory of Chemical Structure," *BJHS* 14 (1981): 27–57. On the numerous chemists whose work made structure theory conceivable, see Rocke, *The Quiet Revolution: Hermann Kolbe and the Science of Organic Chemistry* (Berkeley: University of California Press, 1993). On the role of imagination in attempts to plumb the chemical micro-world, see Rocke, *Image and Reality.*

[23] Crum Brown probably drew inspiration from the diagrams used by his countryman A. S. Couper in 1858. Crum Brown's were the most influential among several styles of graphical formula developed during the early 1860s to express constitution in terms of structure theory. Their success was probably due both to their visual suggestiveness and their comparability to the type formulas in use for the previous decade; Rocke, *Image and Reality*, 118–60.

[24] Whatever their particular commitments with regard to epistemology and chemical theory, as a matter of practice, the majority of nineteenth-century chemists took on this sort of position, which Rocke has termed "chemical atomism";

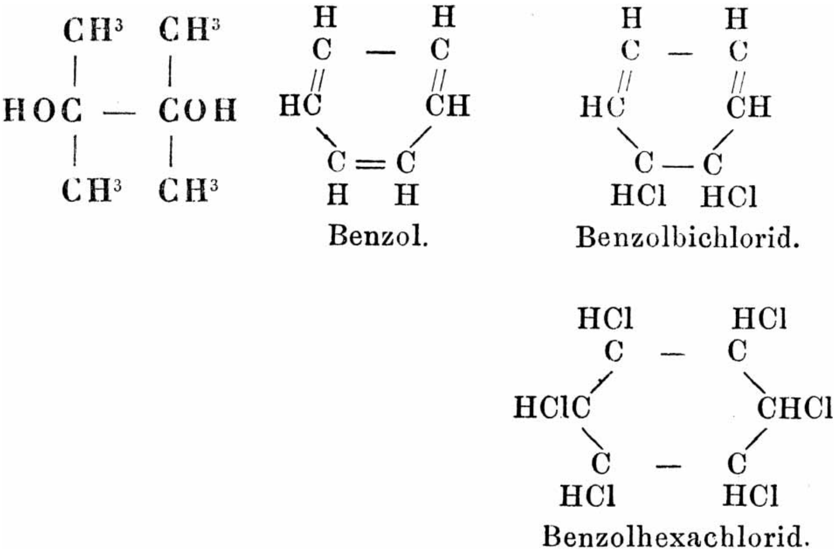

FIGURE 3 Structural formulas used by Geneva delegates Charles Friedel (left) and Carl Graebe (right) in articles of 1869 and 1868, respectively: Charles Friedel, "Recherches sur les Acétones et sur les Aldéhydes," *Annales de la Chimie et la Physique* 16 (1869): 397; Carl Graebe, "Ueber die s. g. Additionsproducte der Aromatischen Verbindungen," *Annalen der Chemie* 146 (1868): 68.

idiom of structure theory, structural formulas were a productive aid to reasoning and teaching.

Structure theory developed in large part through, and in the service of, experiments in which chemists explored constitutional questions raised by valuable naturally occurring substances, using techniques of synthesis. The chemists who carried out such investigations hoped eventually to discover artificial methods of producing such compounds as indigo, morphine, and quinine.[25] However, the proximate goal of these "synthetical experiments" was not typically to prepare a singular target molecule, but to solve particular constitutional puzzles or determine the transformations effected by specific reactions.[26] This involved a shotgun approach: submitting numerous compounds to parallel reactions, and examining the myriad synthetic

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[24] *Continued*
Alan J. Rocke, *Chemical Atomism in the Nineteenth Century: From Dalton to Cannizzaro* (Columbus: Ohio State University Press, 1984).

[25] In 1868, Carl Graebe and Carl Liebermann achieved the first commercially significant natural product synthesis. Their preparation of alizarin, the primary colourant in madder dye, was a pivotal episode in the development of the synthetic dye industry. A. S. Travis, *The Rainbow Makers: The Origins of the Synthetic Dyestuffs Industry in Western Europe* (Bethlehem, London: Lehigh University Press; Associated University Presses, 1993), 163–90.

[26] As Catherine Jackson has shown, Hofmann introduced "synthetical experiments" of this sort during the early 1840s and continued to rely on this mode of research for the rest of his career. Jackson argues that chemists who first succeeded in "constructive synthesis"—the deliberate construction of complex target molecules—during the 1880s did so by means of skilful and innovative laboratory practice, not because of special theoretical insights or particular uses of formula diagrams. Catherine M. Jackson, "Synthetical Experiments and Alkaloid Analogues: Liebig, Hofmann and the Origins of Organic Synthesis," *Historical Studies in the Natural Sciences* 44 (2014): 319–63; Catherine M. Jackson, "The Curious Case of Coniine: Constructive Synthesis and Aromatic Structure Theory," in *Objects*

products that resulted. Some of these novel substances turned out to be valuable dyes in their own right, and the synthetic dye industry that sprang up around these discoveries generated new constitutional puzzles for organic chemists to tackle.[27] Such developments encouraged chemists to expand their synthetic studies, panning the byproducts of their studies of reactions and constitution for chemically interesting or commercially valuable synthetic nuggets.[28]

These broad, comparative synthetic programmes demanded considerable material resources, organisation, and skilled chemical labour. From the 1860s through the 1880s, the conditions for such studies were by far most favourable in German universities, where professors of chemistry worked in well-equipped new laboratories flush with students ready to take up research projects.[29] With no central authority setting curricular standards, these professors could frame their research and instruction as they saw fit; most chose to predict, assess, and express the results of their synthetic studies using structural formulas.[30] The diagrams were at once an expedient means for making claims regarding the real constitution of a new synthetic product—chemists often simply combined the structural formulas of starting materials to illustrate the constitution of such compounds—and convenient bookkeeping devices for keeping track of the expanding taxonomy of organic chemistry.

The chemists who created these compounds sought to coin names that described and classified them in a similar manner. As one German chemist explained, such a procedure "eases comprehension in the highest degree, because the names are constructed entirely according to the formulas."[31] Sometimes, existing conventions of rational nomenclature sufficed, as in the case of Fischer's derivatives of "triphenylmethane," a series of synthetic compounds sharing what he determined to be the core constitutional feature of the synthetic dye magenta.[32] However, many synthetic experiments focused on new reactions and newly determined structural units, producing compounds whose most salient features had no established name. In such

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[26] *Continued*
of Chemical Inquiry, ed. Ursula Klein and Carsten Reinhardt (Sagamore Beach, MA: Science History Publications, 2014), 61–102.

[27] Anthony S. Travis, "Science's Powerful Companion: A. W. Hofmann's Investigation of Aniline Red and Its Derivatives," *BJHS* 25 (1992): 27–44.

[28] Beginning in the 1870s, dye firms began to establish their own research laboratories where they specifically pursued the discovery of such compounds; Travis, *The Rainbow Makers*, 209–30. Physical chemists invoked the prospecting metaphor in critiquing this mode of organic chemical research; John W. Servos, *Physical Chemistry from Ostwald to Pauling: The Making of a Science in America* (Princeton, NJ: Princeton University Press, 1990), 64.

[29] Jeffrey A. Johnson, "Academic Chemistry in Imperial Germany," *Isis* 76, (1985): 500–24; Peter Borscheid, *Naturwissenschaft, Staat und Industrie in Baden (1848–1914)* (Stuttgart: Klett, 1976), 16–82; Rocke, *The Quiet Revolution*, 270–86; Rocke, *Nationalizing Science*, 392–97. Both before and after German unification, the chemical institutes of many Austrian and Swiss universities partook of the same academic culture, if not always such generous state sponsorship.

[30] The broad adoption of structural formulas among German organic chemists during the 1870s is well illustrated by the vigorous but isolated campaign of Hermann Kolbe against their use; Rocke, *The Quiet Revolution*, 325–39.

[31] K. Heumann, "Die Nomenclatur complicirter Azoverbindungen," *Berichte der Deutschen Chemischen Gesellschaft* 15 (1882): 813–14.

[32] Emil Fischer and Otto Fischer, "Ueber Triphenylmethan und Rosanilin," *Justus Liebigs Annalen Der Chemie* 194 (1878): 242–303.

cases, chemists often simply invented their own conventions for putting related fragments of structural formula into words.

Since different chemists often investigated the same classes of substances, this practice tended to produce synonyms. A method for naming one new compound could often be applied to numerous related substances; chemists found it particularly justifiable to do so when competing names had already accumulated, making it difficult to identify those compounds unambiguously. The spreading synonymy generated false structural analogies and obscured intended ones, undermining the ability of these names to convey the constitutional relationships they had been coined to express. The situation was most dire in the areas of greatest chemical interest. Surveying the terms that three dozen chemists had applied to a class of alkaloid constituents and their close chemical relatives, the German-trained Swede Oscar Widman found it "very difficult to keep track of all of these nearly innumerable names, chosen according to different principles, for compounds that are closely related to one another in their constitution, or are even identical" (Figure 4).[33]

Widman and others presented schemes to bring order to the nomenclature of chemical families mired in such confusion. [34] However, these individual proposals rarely mitigated the synonymy and sometimes added to it. No chemists working in the competitive, decentralised, resource-rich settings of German chemistry chose to leave their laboratories to launch sustained, collective action on the matter.

Charles Friedel faced a different challenge.[35] In 1884, thirty years after entering the laboratory of Adolphe Wurtz, Friedel succeeded his deceased mentor as Professor of Organic Chemistry at the Sorbonne. Wurtz and his students had been important early contributors to structure theory; over the succeeding decades, the best of these students formed a close-knit group of French savants who practiced and promoted this approach to chemistry, led by Wurtz and his protégé Friedel. In France, scholarship was centralised in Paris, education tightly regulated by a hierarchical academic bureaucracy, and positivism an influential source of criteria for judging scientific claims. Matters of notation and terminology were particularly hotly debated.[36] Promoting structure theory therefore meant engaging in polemics with sceptical rivals and taking care to establish a firm empirical basis for structural formulas.

To Wurtz and Friedel, who saw their native province of Alsace lost to the newly unified Germany in the Franco-Prussian war of 1870–71, their intellectual cause was

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[33] O. Widman, "Zur Nomenclatur der Verbindungen, welche Stickstoffkerne enthalten," *Journal für Praktische Chemie* 38 (1888): 186–87.

[34] Adolf Baeyer, "Zur Chemischen Nomenclatur," *Berichte der Deutschen Chemischen Gesellschaft* 17 (1884): 960–63; A. Hantzsch, "Untersuchungen über Azole. Allgemeine Bemerkungen über Azole," *Annalen der Chemie* 249 (1888): 1–6.

[35] The following two paragraphs draw upon Rocke, *Nationalizing Science*; Danielle Fauque, "La réception de la théorie atomique en France sous le Second Empire et au début de la IIIe République," *Archives Internationales d'Histoire des Sciences* 53 (2003): 64–112; Ana Carneiro and Natalie Pigeard, "Chimistes Alsaciens á Paris au 19ème Siècle: Un Réseau, Une École?," *Annals of Science* 54 (1997): 533–46.

[36] See, for instance, the detailed discussion of debates over the meaning of the terms "atomicity," "equivalent," "atom," and "molecule," and of controversies over notation, in Fauque, "La réception de la théorie atomique."

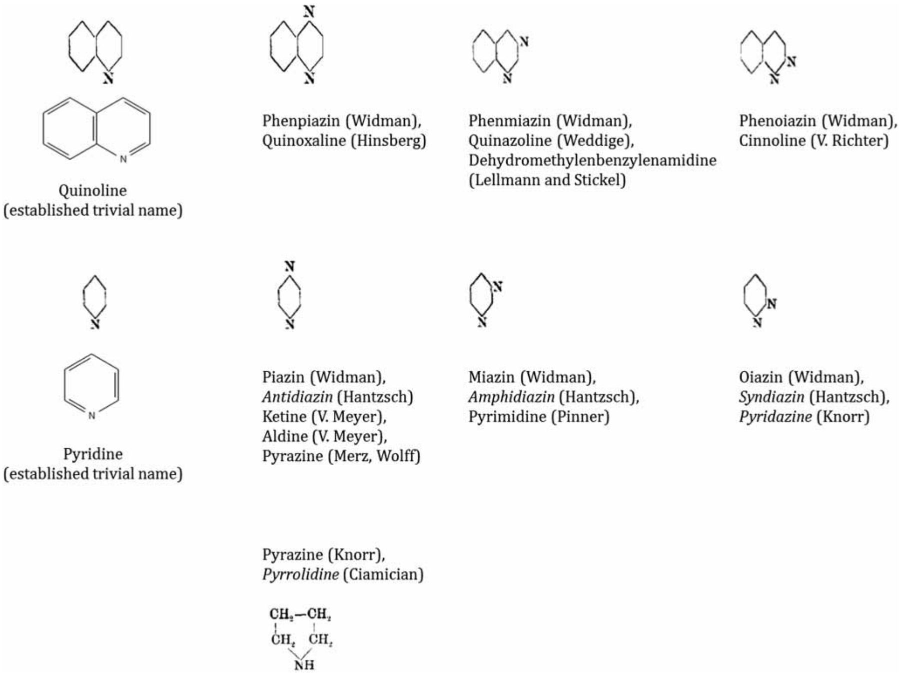

FIGURE 4 Competing rational names for some nitrogen-containing ring compounds. All names and original diagrams are from Widman except for names in italics, from Hantzsch. Structural formulas for pyridine and quinoline, drawn according to present-day conventions, are provided for reference. Unlabelled vertices of structural formulas indicate carbon atoms, and hydrogen atoms are omitted, except for the last. Widman, "Zur Nomenclatur"; A. Hantzsch, "Zur Nomenclatur stereoisomerer Stickstoffverbindungen und stickstoffhaltiger Ringe," *Berichte der Deutschen Chemischen Gesellschaft* 24 (1891): 3479–88.

also a patriotic one. Many French savants and statesmen blamed the disastrous defeat on the decline of French science and technology relative to their German counterparts. Wurtz and Friedel contended that only through embracing atomism and structure theory (and upgrading the nation's poorly equipped academic laboratories) could French chemical science and industry advance.

By the 1880s, Wurtz, Friedel, and some of their students managed to introduce structure theory into their teaching, especially in the provinces, but their goal of establishing it within the general French chemical curriculum remained elusive. Friedel remarked:

> Although science advances fairly rapidly, public education, in its prudent march, struggles to follow this movement, especially in our country, bound to uniformity in its very organization. … [T]he language itself must be transformed to express the new ideas, and nothing is more difficult to accept than a change of language.[37]

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[37] Charles Friedel, introduction to Charles Adolphe Wurtz, *La Théorie Atomique*, 4th ed. (Paris: F. Alcan, 1886), xxv–xxvi.

In 1888, Friedel seized the following year's Universal Exposition in Paris as an opportunity to begin such a transformation. He organised an International Congress of Chemistry, to be held during the Exposition; one of the sections of the Congress addressed the "unification of chemical nomenclature and notation."[38] Chemists from nine different nations participated, but the vast majority were French, and Friedel and his students dominated the nomenclature discussions.[39] They also took the reins of the International Commission formed to continue the study of nomenclature in preparation for a future Congress. This Commission, chaired by Friedel, included representatives from fourteen nations, but it immediately delegated the task of developing specific proposals to a specially designated Subcommission. The Subcommission consisted of Friedel; his fellow former Wurtz students Armand Gautier and Édouard Grimaux; three of Friedel's own students, Alphonse Combes, Auguste Béhal, and Adrien Fauconnier; and Louis Bouveault, a student of Wurtz disciple Maurice Hanriot.[40]

Two years and forty-five meetings later, the Subcommission prepared to submit its report to a different kind of Congress. For the Geneva Congress, in contrast to the Paris meeting, Friedel took pains to secure the participation of an influential collection of chemists, including some of the most prominent Germans struggling with the challenge of synonymy.[41] Such a group taking up such carefully crafted proposals could dare to hope that its collective effort to reform chemical nomenclature might succeed.

Yet these delegates brought distinct motives and perspectives to this collective effort. Friedel and his French colleagues wished to reform the language in which chemistry was taught, while Baeyer and his fellow Germans wanted to find a more certain means of documenting the identity of chemical substances and the relationships among them. Although the delegates had similar ideas regarding the epistemic reliability and limits of structure theory, the use of structural formulas was a matter of habit as well as epistemology. Encouraged by the rapid pace of synthetic chemistry, and enabled by their relative scholarly and pedagogical autonomy, German chemists used structural formulas confidently, both as tools of visual reasoning, as if they were mimetic representations, and as bookkeeping devices for cataloguing chemical subunits. The French atomists were no less attached to structural formulas, but in the disputatious arena of Parisian science, they had to be ready to fend off challenges to the legitimacy of these diagrams. In order to do so, they were accustomed to keeping structural formulas in close contact with the

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[38] Minutes of Council, 31 July 1888, Procès-Verbaux de la Société Chimique de Paris, Cahier 2, 77–79, Archives de la Société Chimique de France. On international scientific congresses in the late nineteenth century, see the essays collected in Brigitte Schroeder-Gudehus, ed., "Les Congrès Scientifiques Internationaux," *Relations Internationales* 62 (1990): 111–211.

[39] Untimely distribution of invitations reportedly contributed to the modest international attendance; "The International Chemical Congress," *Nature* 40 (1889): 369–71. Whether accidental or intended, the paltry international showing helped Friedel and his students maintain control of the proceedings.

[40] Alphonse Combes, "Le Congrès International de Nomenclature Chimique," *Revue Générale des Sciences Pures et Appliquées* 3 (1892): 258 n1.

[41] For example, eight of the best-known chemists mentioned in Widman's article were invited; three attended.

experimental evidence on which they were based.[42] At the Geneva Congress, these separate motives for reform and practices of graphical representation shaped two distinct visions of how and where systematic nomenclature should work.

Making nomenclature official

On Tuesday morning, the delegates climbed the hill of the old city to the Salle du Grand Conseil for the Congress's opening session.[43] Friedel began the morning's proceedings by introducing the fifty-three page report that his Subcommission had prepared. The report expressed a bold reinterpretation of the Commission's original mandate. Instead of seeking to unify the nomenclature of particular families of compounds, Friedel's group had conceived an entirely new understanding of nomenclature that would unite the names of all organic chemical substances under a system governed by a few key principles. Before the morning's session was through, however, Friedel's plan would be supplemented and in part supplanted by Adolf von Baeyer's vision of how and where such a system of names should work.

The Paris Congress had charged the International Commission it created with unifying the uncertain nomenclature of three groups of complex compounds.[44] In its report, the Subcommission explained that in order to carry out these tasks, it found itself compelled to consider two further matters:

> (a) The rules to follow in naming each chemical function by a consistent suffix or a prefix inserted into the name;
>
> (b) The designations to apply to radicals and in general to functional groups most often present in molecules.[45]

The Subcommission members decided that they could not unify the nomenclature of complex substances without first setting out rules for naming their simpler component parts. This meant, however, that the Subcommission's proposals would address not only the substances at the leading edge of synthesis that had prompted the reform effort, but also simple compounds with well-established names. Friedel and his colleagues were open about this aim: "the propositions adopted by the Subcommission, at the end of numerous meetings … allow, we believe, the clear, succinct, and unambiguous naming of all known organic chemical substances."[46] Friedel and his Subcommission had been tasked with unifying the outer reaches of chemical vocabulary, but they proposed a universal grammar for forming acceptable chemical names.

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[42] On the speculative use of structural formulas by German organic chemists, see Rocke, *The Quiet Revolution*, 325–39.

[43] "Réunions-Convocations-Concerts," *Journal de Genève*, 19 April 1892, 3.

[44] Specifically, compounds with rings containing nitrogen or other non-carbon atoms (Widman's area of concern), compounds with multiple different functional groups, and benzene derivatives.

[45] "Rapport de La Sous-Commission," 393–95. A "functional group" was (and is) understood as a discrete structural subunit within a chemical formula that was associated with a particular chemical behaviour.

[46] "Rapport de La Sous-Commission," 393.

The Subcommission framed seven principles to guide its pursuit of this ambitious goal:

1. Change current nomenclature as little as possible, except to complete and standardise it in order to avoid confusion and superfluous synonyms.
2. As much as possible, found the laws of the reformed nomenclature on the general principle of *substitutions*, except where it's necessary to express a direct addition.
3. In all of the names of derivatives of the same family—of the same hydrocarbon, the same alcohol, etc.—include a shared root that indicates their relationship and their parent.
4. Express the groups which characterise the functions of these molecules by prefixes and suffixes added to this root.
5. Conserve established names such as camphor, xylene, naphthalene, and terebine as roots, without indicating the structure of these familiar compounds or radicals.
6. As much as possible, adopt or construct names that are spoken and written according to the chemical formula, separating out each radical and indicating their positions following a fixed order.
7. Conserve common names such as alcohol, camphor, chloral, quinine, indigo, tyrosine, and urea, since they have passed into regular usage, but without prejudice against the corresponding new names.[47]

This was a blueprint for nomenclature reform that took into account both the benefits of rational nomenclature and the drawbacks of replacing established terms with neologisms. The second and sixth of these principles tethered the new nomenclature to structure theory and its diagrams. The name of an organic compound would follow the architecture of its structural formula, divided according to the principle of substitution into substituent radicals and a core corresponding to a parent compound. The third and fourth principles articulated the linguistic form in which the reformed names would express chemical relationships. Substitution products derived from the same parent compound would share a root, and compounds possessing the same chemical function would share a prefix or suffix. These were familiar conventions for forming rational names, but they had not previously been stated formally or applied generally.

Decades of experience had taught the French reformers how resistant their colleagues could be to changes in notation that appeared unjustified. Friedel and his band therefore took care to rein in their reformist impulses with the first, fifth, and seventh principles, which expressed a commitment to retaining established names that were not direct sources of confusion. Collectively, the Subcommission's principles described a reform that was sweeping in scope but accommodating

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[47] "Rapport de La Sous-Commission," 393–94. Those interested in fine gradations of language will note that the Subcommission distinguished technical names that refer to a chemical compound without specifying its structure, mentioned in the fifth of these principles, from chemical names either derived from or passed into regular nontechnical usage, mentioned in the seventh. This distinction corresponds approximately to the distinction between *trivial* and *common* chemical names, though the former class arguably includes both sets of names.

toward habit, sanctioning chemical names that the Subcommission members hoped would prove “universally accepted, simple, clear, and lasting.”[48]

Previous proposals addressing organic chemical nomenclature had always addressed the naming of some particular set of compounds. So, too, did the questions that Friedel’s Subcommission had been charged with answering. *Nomenclature* was always succeeded by *of*; nobody spoke of organic chemical nomenclature in general. Friedel and his Subcommission changed this. The scheme that Friedel presented at the outset of the Geneva Congress redefined nomenclature as a collective lexicon addressed at once to all organic substances. Order was to be established within this field in three ways: through a unit-by-unit correspondence between name and structural formula; through establishing such correspondence in a consistent fashion across many different classes of substances; and through a conservative commitment to preserving familiar names that had proven to be clear and useful.

Having laid out this approach to nomenclature reform, Friedel opened the floor for discussion of the particular recommendations that made up the bulk of the report. Baeyer, however, was not yet ready to move on. He requested that, prior to entering into a detailed discussion of any particular family of compounds, the Congress answer a few basic questions that had not yet been settled to his satisfaction. Which settings required nomenclature reform most urgently? What principles did the Congress need to prioritise in order to ensure that the new names were effective in these settings? How far was the reform to extend?[49]

Friedel and his fellow Subcommission members had sought to accommodate the various demands that might be placed on names by building flexibility into their scheme. They proposed allowing chemists to select among various nomenclature procedures that could apply to a compound.[50] In response to Baeyer’s challenge, Friedel and his colleagues remarked that this freedom of choice was especially useful in pedagogical settings, enabling an instructor to highlight the various chemical functions of a compound using different names. They cited the example of aniline, a compound of vital importance in chemical research and manufacturing. Different aspects of the chemical behaviour of aniline were associated with two structural units, an amine functional group and a benzene core. By referring to the substance as *phenylamine* or *aminobenzene*, an instructor could emphasise either of these properties and the chemical relationships that it entailed.[51]

Baeyer, however, was primarily concerned with establishing a reformed nomenclature for the purposes of chemical lexicography. In his view, the demands of indexing were so pressing that the Congress should focus *exclusively* on establishing for each compound “an official name, the translation of its constitution,

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[48] “Rapport de La Sous-Commission,” 398.

[49] Pictet, “Congrès International,” 489–90; Amé Pictet, Minutes of the Geneva Congress (manuscript), 170, Bibliotheque de Genève, MS Fr. 3423.

[50] “Rapport de la Sous-Commission,” 397–98.

[51] Pictet, “Congrès International,” 489.

which would permit it to be retrieved easily in tables and dictionaries."[52] The length and euphony of these official names would be relegated to secondary considerations. In journal articles, lectures, classrooms, and other settings where such concerns were significant, chemists would remain free to use whatever names they wished.

After a long discussion with Lieben, Bouveault, and Friedel, Baeyer won the assent of the President and the other delegates to his plan. The Congress agreed unanimously to adopt Baeyer's version of systematic nomenclature as its first resolution: "Alongside the usual procedures of nomenclature, an official name will be established for each organic compound, permitting it to be found under a unique heading in indexes and dictionaries."[53] With that, they broke for lunch.

The decision amounted to a division of the field of nomenclature which the Subcommission had defined as the object of its proposals. The notion of a field encompassing the names of all organic substances remained, cast as "the usual procedures of nomenclature." Following Baeyer's lead, the Congress carved out a separate field of "official names," whose application was restricted to reference works. The Subcommission's vision of order, however, no longer applied to either field. Within the compass of indexes, Friedel's commitments to lexical conservatism and flexibility were trumped by the imperative of forming unique names.[54] Elsewhere, on the other hand, the Congress would not attempt any reform at all.

The Congress secretary Amé Pictet summarised:

> We will continue to say alcohol, chloroform, sugar, and the chemist who, either in his articles or in the classroom, would use the expressions 'ethanol,' 'trichloromethane,' and 'hexanal-pentol,' which are henceforth the official names of these three substances, would fall into the same ridiculous pedantism as the botanist who in normal conversation employed the term 'brassica oleracea' to designate 'un chou' [a cabbage].[55]

The structure of chemical function and the function of chemical structure

The group reconvened that afternoon at the Hotel Métropole, where the remaining six sessions of the Congress were to be held. Having established their aim—a set of rules for constructing a unique, official name based on the constitution of each organic compound—they had to work out how to achieve it.[56] This was a question

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[52] Pictet, Minutes (manuscript), 170. Prior to the Geneva Congress, Baeyer submitted a proposal for determining unique names to the Subcommission; the Subcommission considered but rejected this proposal, along with an alternative prepared by Subcommission member Louis Bouveault. However, the Subcommission members had not understood Baeyer to be proposing that the reformers *restrict* their efforts to establishing such a system of official nomenclature; "Rapport de La Sous-Commission," 394.

[53] Pictet, "Congrès International," 490–91.

[54] Pictet accordingly edited the Subcommission's list of guiding principles for his official report, eliminating those that mentioned conserving existing names. Compare "Rapport de La Sous-Commission," 393–94 and Pictet, "Congrès International," 491.

[55] Pictet, Minutes (manuscript), 168.

[56] Pictet, Agenda, entry of 19 April 1892.

of the relationship between name, formula diagram, and substance. Once again, the Geneva delegates arrived at a different answer than that proposed by the Subcommission. In doing so, the Congress articulated a distinctive way of thinking about structural formulas that shaped the use of these diagrams and helped bring about their remarkable persistence.

The first item on the session's agenda was the saturated hydrocarbons: compounds made up of carbon atoms linked in open chains, with all of their remaining units of valence taken up by hydrogen atoms. They were commonly named in several different ways, but these names were well established and caused little confusion. In its report, the Subcommission paid little attention to these simplest and least reactive of organic compounds.

Tasked with forming official names, the Geneva delegates had to be more particular. They quickly agreed that Hofmann's well-known names—*ethane*, *pentane*, and the like—should be uniquely assigned to the "normal" isomers whose carbon atoms were arranged in a linear chain. As for the branched isomers, Lieben thought that the Subcommission's approach to a different set of compounds might be of use. For the special case of open-chain compounds containing multiple functional groups, the French chemists had adopted a more rule-bound alternative to their flexible method. Béhal, the author of this portion of the report, proposed taking the longest linear chain of carbon atoms in the compound's carbon "skeleton" as a starting point, numbering the carbon atoms of this chain from one end to the other. The name of the hydrocarbon corresponding to this chain would serve as the root of the name of the compound. Each functional group would be indicated by a prefix or suffix, along with the number of the skeleton carbon atom to which it was attached.[57]

In Lieben's view, branched hydrocarbons could be named by an analogous process: locating the longest carbon chain in the structural formula, taking the name of the hydrocarbon corresponding to this "principal chain" as a root, and then naming the remaining "side chains" as if they were functional substituents.[58] Baeyer suggested adopting Béhal's method of numbering for the branched hydrocarbons, as well. In view of the imperative of generating unique names, their fellow delegates agreed to the propositions.

Baeyer had further plans for these simple compounds. He called on the Congress to make the rules for naming hydrocarbons the basis of its entire system, applying them as a first step in naming any organic compound. Béhal disagreed, proposing instead to consider the position of functional groups as the starting point for determining a compound's name. He contended that this would make for a more straightforward naming process, shorter names, and—most importantly—names that more clearly expressed the compound's chemical behaviour. Baeyer countered that unlike

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[57] "Rapport de La Sous-Commission," 414–16.

[58] Pictet, "Congrès International," 493–94.

such "functional nomenclature," his procedure would ensure consistent naming and numbering among different derivatives with the same carbon skeleton.[59]

After some debate, the delegates approved Baeyer's proposal. As a result, no matter what the substance, the Geneva rules latched on to it through the "ensemble of atoms of carbon directly bonded to one another, forming an invariable skeleton, which is found in all the compounds derived by substitution of the hydrocarbon that contains it."[60] The Geneva rules generated consistent, unique names through the application of a consistent, even algorithmic procedure: take a compound's structural formula, reduce it to a carbon skeleton, identify the longest chain in that skeleton, and so on through fourteen rules of hydrocarbon nomenclature before moving on to functional groups. The Geneva nomenclature was systematic in process as well as product.

For example, take pinacone, a compound produced by the coupling of two molecules of acetone. When Friedel studied this substance in the 1860s, in addition to its established trivial name, Friedel assigned it the name *tetramethyl ethylglycol*. He selected the root "glycol" in order to emphasise the compound's chemical function—a set of properties and characteristic chemical reactions that Friedel had established through painstaking experiment. The Subcommission's report advocated names that directly expressed such analogies in chemical behaviour.[61]

In contrast, a chemical editor applying the Geneva rules to name pinacone would begin with its structural formula (Figure 5). Setting aside the two alcohol functional groups, he would identify the longest chain within the carbon skeleton and select the name of the saturated hydrocarbon corresponding to this four-carbon chain, *butane*, as a root (Figure 5, I). Treating the two remaining carbon atoms as side chains, he would use the single-carbon substituent prefix *methyl-*, adding *di-* to account for both of them, forming *dimethylbutane* (Figure 5, II). After numbering the principal chain, he would arrive at the full name of the hydrocarbon skeleton, *2,3-dimethylbutane* (Figure 5, III). With the skeleton taken care of, he would then turn to the –OH groups. Adding *di-*, for the two groups, to the functional suffix –*ol*, and using the numbering determined by the hydrocarbon skeleton, he would complete the official name for pinacone, *2,3-dimethyl-2,3-butanediol* (Figure 5, IV). At no point in the process was empirical study of the properties of the compound to be taken into account. Instead, the relationship between the Geneva name of an organic compound and its functional behaviour and relationships was mediated by the Geneva rules and the structural formulas on which they operated.

The difference between the Subcommission's and the Congress's views on the relationship of formula, name, and substance was illustrated more sharply still in the treatment of unsaturated hydrocarbons, in which one or more pairs of adjacent carbon atoms were linked by two or three bonds rather than "saturated" with bonds

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[59] Auguste Béhal, "La Nomenclature Chimique au Congrès International de Genève," *Moniteur Scientifique* 39 (1892): 412–13.

[60] Alphonse Combes, "Le Congrès International," 258.

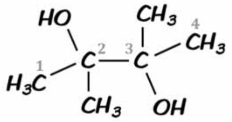
[61] Friedel, "Recherches sur les Acétones," 322, 390–97.

pinacone

(I) butane

(II) dimethylbutane

(III) 2,3-dimethylbutane



(IV) 2,3-dimethyl-2,3-butanediol

FIGURE 5 Naming pinacone according to the Geneva rules.

to hydrogen atoms. As Pictet reported it in the proceedings of the Congress, Baeyer's proposal for naming unsaturated hydrocarbons was an incontestable correction of a surprisingly fundamental oversight by the Subcommission. The French chemists had recommended adopting Hofmann's system, which used the suffixes *–ene, –ine, –one*, and *–une* to indicate compounds with two, four, six, and eight hydrogen atoms fewer than their saturated analogues.[62] However, this approach named compounds according to their molecular composition, not their structure, violating one of the Subcommission's own guiding principles. For instance, Hofmann's system did not specify whether a name ending in *–ine* referred to a compound containing one double bond or two triple bonds, or where those bonds were located within the compound's carbon chain. Instead of the general absence of two or four hydrogen atoms, Baeyer recommended that the suffixes *–ene* and *–ine* represent the specific presence of a double and triple bond, respectively.[63] The delegates immediately accepted this proposal.

The Subcommission's failure to adopt rules specifying the location of double and triple bonds was puzzling. It was not for lack of awareness of the issue: Béhal's dissertation, which Friedel supervised, specifically dealt with the thorny experimental problem of pinning down the position of such bonds.[64] Further, the Subcommission

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[62] "Rapport de La Sous-Commission," 400–1.

[63] Pictet, Minutes (manuscript), 171–72; Pictet, "Congrès International," 497–98. Since the two suffixes were indistinguishable when pronounced in English, the suffix "ine" was later exchanged for "yne."

[64] Charles Friedel, "Rapports Sur Les Thèses de Doctorat d'État, 1881–1889," 800–2, AJ/16/5534, Archives Nationales, Pierrefitte-sur-Seine.

followed its endorsement of Hofmann's nomenclature with an addendum suggesting names expressing the constitution of unsaturated compounds to be used when needed to avoid confusion with other names ending in *–ine* or *–one*.[65] Why did the Subcommission recommend a procedure that did not live up to its goal of rational nomenclature, when an alternative that did was sitting three paragraphs below in the same report?

The introduction to the Subcommission's discussion of hydrocarbons suggests an answer:

> We believe that we need to give to each of the classes of hydrocarbons, saturated, bivalent, quadrivalent, etc., suffixes which mark their valence, this having been measured by the number of atoms of chlorine or bromine or double the number of molecules of hydracids that each hydrocarbon is able to accumulate in its molecule, *without substitution and without the molecule losing its ability to return to its original state.*[66]

For the Subcommission, the valence of an unsaturated hydrocarbon was grounded not in a feature of a structural formula, but in experiment. The procedure described above offered a straightforward method for determining valence, whereas it could be difficult to determine the specific location of a double- or triple-bond in a carbon chain, as Béhal and Friedel knew first hand. If a compound's constitution could be established in the former manner but not the latter, the Subcommission provided a mechanism for assigning it a name that expressed as much of its constitution as had been determined. Without a unique, complete structural formula, however, such a compound could not be named at all by the Geneva rules.[67]

A further reason for this approach was epistemic caution. Friedel and his collaborators wished to avoid creating names that expressed a degree of structural detail not warranted by experiment. They wrote:

> Instead of employing interminable, obscure names, often founded on dubious hypotheses and incomplete and uncertain proofs, names having the pretension of expressing definitively the entire constitution of the compound, it would be better, in general, to limit ourselves to expressing clearly by the name of the substance its relationships with the other substances of the natural family to which it is known to belong and its characteristic and experimental functional properties.[68]

The Subcommission members saw the value in names that expressed "the entire constitution" of compounds. But heeding the tenuousness of many determinations of chemical structure, they took care not to reach beyond experimentally attested properties and relationships in order to do so.

"What is important above all," Pictet wrote in summarising the decisions of the Geneva Congress, "is that the official name be the faithful translation of the

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[65] Specifically, those of alkaloids such as morphine, quinine, and nicotine, and ketones such as acetone.

[66] "Rapport de La Sous-Commission," 400. Emphasis in original.

[67] The Congress explicitly restricted the scope of its rules to compounds whose structure had been determined; Pictet, "Congrès International," 492.

[68] "Rapport de La Sous-Commission," 398.

constitution of the compound, and that it represent the constitution to the mind just as the structural formula does."[69] Over their two years of labour preparing for the Congress, Friedel and his fellow Subcommission members had also sought to develop chemical names that worked "just as the structural formula does." The distinct relationships that the Subcommission and the Congress hoped to forge between name, diagram, and substance reflected the differing goals of each group.

Friedel and his allies aimed to reinforce the teaching of structure theory in France in a manner that could resist the dogged criticism of atomic sceptics. To that end, they crafted proposals for a nomenclature that expressed experimentally determined chemical behaviour through the interpretive lens of structure theory, just as their structural formulas did. According to the Subcommission's proposal, systematic names and formula diagrams would each represent organic compounds in the same manner, grounded ultimately in observations of chemical function.

Baeyer's goal, in contrast, was to bring the advantages of structural formulas to bear on a problem to which the diagrams themselves could not be applied: determining a unique heading for each compound in an alphabetically ordered index. Guided by Baeyer and Lieben, the Geneva delegates built a set of rules for systematically disassembling a structural formula and naming and numbering its pieces in a determined order, such that the process could be reversed to regenerate the diagram from the official name. The proximate referent of a name formed according to the Geneva rules was not the compound at all, but the structural formula. Geneva names stood in for structural formulas where the latter could not be used and summoned these diagrams, when needed, to represent the compounds themselves.

A "solid and durable foundation"

The discussion of the open-chain hydrocarbons occupied the entire Tuesday afternoon session and most of Wednesday morning; the resulting set of rules constituted the general framework of the Geneva nomenclature. The approach departed from the spirit of the Subcommission's report, but Friedel and his cohort did not express dissatisfaction—at least not on the record. After all, if they had conceded the battle for the form of the new nomenclature, they were winning the war of convincing the assembled chemists to agree upon *some* collection of nomenclature rules.

This achievement was possible in large part through the intimacy and collegiality of the Geneva Congress. British delegate Henry Armstrong wrote of the Congress's opening days:

> The great advantage to be derived from the personal intercourse which such meetings promote was soon apparent: gradually, the doubts which many entertained as to the possibility of devising a practical rational scheme of nomenclature were dispersed,

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[69] Pictet, "Congrès International," 491.

> and ere many hours had elapsed the sympathies of all present were enlisted on behalf of the work.[70]

Much of this "personal intercourse" took place outside of the Congress's twice-daily official sessions. After dining together on Tuesday evening, the chemists proceeded to the theatre, where the Geneva minister of education invited them to join him in his lounge and box. The evening's show, the well-known fairy comedy *Le Pied du Mouton*, allowed the delegates to focus their attention on conversation and champagne.[71]

The next evening, the delegates assembled for the official Congress banquet, joined by several of their wives and a number of local dignitaries.[72] As the guests dined on a main course of "sirloin à la nomenclature," Graebe toasted Friedel for his leadership in the nomenclature reform effort. Friedel, in turn, toasted Graebe, Geneva, and Switzerland for their amiable welcome.[73] Baeyer toasted the successive roles played by France and now Germany in driving the discipline of chemistry forward, and drank to whichever nation would next claim the laurels.[74] The evening concluded with a nightcap at a nearby haunt, the *Taverne du Crocodile*.[75]

Reflecting on the meeting years later, Emil Fischer contrasted the series of "noisy and confusing" congresses of applied chemistry inaugurated in 1894, which he "avoided if at all possible," with the Geneva Congress, whose distinctive social and intellectual dimensions made the thirty-four chemists in attendance feel "like one big family."[76] Such ties also encouraged the delegates to put their professional authority behind the resulting Geneva rules, uniting the assembly as "a mission … which will explain the enterprise to chemists generally," as Armstrong put it.[77]

In order to take advantage of these favourable circumstances, however, the Congress had to work quickly. As Wednesday drew to a close, the delegates had dispatched only a fraction of the simple organic compounds containing a single functional group, and Baeyer, Lieben, Fischer, and others were set to depart the following day. Stanislao Cannizzaro, one of the Congress vice-presidents, proposed nominating another commission to deal with the many matters that seemed sure to remain unresolved.[78] But leaving Geneva without at least a reasonably complete

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[70] Armstrong, "International Conference," 57.

[71] As Pictet put it in his diary, "Le pied de mouton, pièce à grand spect mais pas spir. … Passé presq tt mon temps avec eux dans le salon du cons d'Etat à boire du Champ. Longue conv avec Em Fischer." Pictet, Agenda, entry of 19 April 1892. *Le Pied du Mouton* (literally, "The Sheep's Foot") was a French comedy written in 1806, featuring slapstick comedy, fairies, and spectacular effects. It was popular throughout the century, especially with middle- and lower-class audiences, and was adapted as a film in 1907; Jack Zipes, *The Enchanted Screen: The Unknown History of Fairy-Tale Films* (New York: Routledge, 2011), 37–38.

[72] At the turn of the twentieth century, the wives of scientists often accompanied their husbands on professional travel. On the road, as at home, both spouses participated in constituting a gendered lifestyle that shaped the production of scientific knowledge; Staffan Bergwik, "An Assemblage of Science and Home: The Gendered Lifestyle of Svante Arrhenius and Early Twentieth-Century Physical Chemistry," *Isis* 105 (2014): 265–91.

[73] "Chronique Locale. Congrès de Chimie," *Journal de Genève*, 22 April 1892, 3.

[74] Armstrong, "International Conference," 56–57.

[75] Pictet, Agenda, entry of 20 April 1892.

[76] Emil Fischer, *Aus Meinem Leben* (Berlin: Springer, 1922), 135.

[77] Armstrong, "International Conference," 57.

[78] Pictet, Minutes (manuscript), 175.

system of nomenclature would mean missing the opportunity to establish the new names in the forthcoming edition of Beilstein's *Handbuch* and other settings in which they could be disseminated and tested.

When Friedel brought up the acid anhydrides as the final order of business on Wednesday, Graebe proposed that the "current mode" of designating these substances be retained.[79] This set the pattern for the Congress's final two days, in which the delegates switched gears from intensive debate to churning out resolution after resolution, either rubberstamping Subcommission recommendations or conserving "the current nomenclature." A dispute between Friedel and Baeyer over what actually constituted one such "current practice" might have given them pause.[80] However, any such qualms seem to have been outweighed by the imperative of bringing as many compounds as possible within the compass of the Geneva rules. In their final substantive meeting on Friday morning, after half of the delegates had departed, the remaining attendees approved Combes' long proposal for numbering benzene derivatives in its entirety, without any discussion.[81] They were persuaded, Pictet wrote, by the "simplicity and precision of the notation that he proposed." Exhaustion, the lack of time for further debate, and a determination to broaden the officially sanctioned nomenclature as far as possible probably played just as great a part.[82]

For several chemical families, including compounds with more than one variety of functional group, the delegates were unable to reach a consensus. Nor could they elect to sanction current practice, for these compounds had no well-established names. Further, the delegates decided that they could not responsibly ignore the demands of general usage when any rule they ratified would be the only available standard for such usage. In reserving the naming of such compounds for further study, the Congress called for an "attempt to reconcile the exigencies of spoken nomenclature with those of a terminology applicable to dictionaries."[83] Choosing to create a nomenclature expressly for dictionaries had freed the delegates from worrying too much about cumbersome names that its rules might create; they were just for indexes, after all, not for use in other settings. For this reason, however, the Geneva delegates came up short where generally recognised names had not yet been established—precisely those sets of compounds whose nomenclature the International Commission had originally been tasked with unifying.

This irony did not much bother the Congress attendees. They had come to Geneva not to criticise nomenclature reform, but to carry it out. They carefully limited the scope of their project to "official" nomenclature and prioritised the development of consistent rules to determine a unique name for any compound whose structure

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[79] Pictet, Minutes (manuscript), 175.

[80] The disagreement pertained to the usual meaning of the prefixes "sulfo" and "thio"; Béhal, "Nomenclature Chimique," 414.

[81] Pictet, Agenda, entry of 22 April 1892.

[82] Pictet, "Congrès International," 512–19. The delegates did elect to set aside some difficult questions regarding the position of benzene in the Geneva rules' order of operations.

[83] Pictet, "Congrès International," 509–11, 519–20.

was relatively simple. They set aside for further study questions of how to extend these rules to determine unique names for more complex compounds, including most of those that Friedel's Commission had been created to address. According to Pictet, the assembled chemists felt that, despite the limited scope of their achievements, "the results achieved so far are nonetheless of considerable importance, and the International Congress of Geneva, in establishing the principles of the official nomenclature, will have laid a solid and durable foundation for the reform that it intended to accomplish."[84] The delegates departed Geneva satisfied that their rules of nomenclature were complete enough to be applied and robust enough to build upon.

Conclusion

The Geneva Congress did more than introduce a new set of names for organic chemical compounds, or even a new way of naming them. Over four days in April 1892, Europe's greatest authorities on organic chemistry crafted a new conception of chemical nomenclature, and a new relationship between chemical names, structural formulas, and chemical substances.

Shifts in how chemists used and coined names during the 1870s and 80s had made nomenclature reform conceivable. The practice of basing the names of substances on their structural formulas provided a means; the subsequent proliferation of confusing synonyms provided a motive. But the Geneva Congress actually came to pass through the considerable efforts of Charles Friedel, who was distinctively positioned to see nomenclature reform as an opportunity to advance the causes of France in chemical science and industry and of structure theory in France.

In laying the groundwork for Geneva, Friedel and his band of students and associates redefined nomenclature not simply as the collected vocabulary of chemists but as a continuous field that could be made subject to a flexible grammar grounded in the constitution of chemical compounds, just as structural formulas were. Guided by lexicographic rather than pedagogical concerns, Adolf von Baeyer convinced the delegates of the Geneva Congress to redefine nomenclature once again, dividing it into a sphere of general usage, to be left to its own devices, and a realm of official nomenclature, where each name was a precise and unique transcription of a structural formula diagram.

Neither Friedel nor Baeyer intended this form of nomenclature to replace well-established trivial names, and indeed, it never did.[85] But the correspondence of name to structural formula, a proximate relation into which the substance itself did not enter, quickly became the characteristic feature associated with chemical names.[86] Alexander Crum Brown, who had been among the first chemists to use

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[84] Pictet, "Congrès International," 520.

[85] Present day international nomenclature guidelines sanction the use of certain trivial names, called "retained names"; *Nomenclature of Organic Chemistry: IUPAC Recommendations and Preferred Names 2013*, ed. Henri A. Favre and Warren H. Powell (Cambridge: Royal Society of Chemistry, 2014), 9.

[86] "To be useful for *communication* among chemists, nomenclature for chemical compounds should additionally contain within itself an explicit or implied relationship to the structure of the compound, in order that the reader

structural formulas, recognised this. Discussing the Geneva Nomenclature two months after the Congress, he observed, "We must keep in mind that such systematic names as had been suggested were really names of formulas rather than names of substances."[87]

This entailed not only a different kind of chemical name but a different manner of reading a structural formula. The rules of the Geneva nomenclature did not operate on the chemical properties and relationships that the formula expressed, but on regularities inherent to the diagrams: patterns of connection among atomic symbols that provided purchase for a logical order of operations mapping diagram to name. This way of thinking about structural formulas would subsequently shape not only such "paper tools" as Robert Robinson's electron displacement arrows, but also print, mechanical, and electronic technologies for managing chemical information.[88]

That was all to come. The immediate response to the Geneva Nomenclature was a flurry of adoption, followed by a rising tide of scepticism. Pictet published his French-language account of the Congress and its resolutions in May 1892. Translations of the Geneva rules in English, German, Italian, Russian, and Romanian soon followed.[89] Beilstein adopted Geneva names in his *Handbuch*, to the delight of the French.[90] Notwithstanding the Congress's decision to restrict the application of its rules to reference works, some delegates proposed using or adapting them for teaching.[91] One even wrote a textbook that used exclusively Geneva names.[92]

Meanwhile, the chemical editors for whom the Congress had tailored its resolutions were growing frustrated with the Geneva nomenclature. The rules were complicated, the names long and awkward, and most of the compounds of interest to their authors and readers were not even covered. Some, such as the new editors of the *Berichte*, the influential journal of the German Chemical Society, chose to stop using the official names at all.

The German editors based their decision on the relationship that the Geneva approach forged between name, diagram and substance—and on the effects of *this* relationship on relations among chemists:

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[86] *Continued*
or listener can deduce the structure (and thus the identity) from the name" (emphasis in original). Robert Panico et al., *A Guide to IUPAC Nomenclature of Organic Compounds: Recommendations 1993* (Oxford: Blackwell Scientific Publications, 1993), xiii.

[87] *Proceedings of the Chemical Society* 8, no. 114 (16 June 1892): 130.

[88] On Robinson's arrows: Nye, *From Chemical Philosophy to Theoretical Chemistry*, 191–92. On early approaches to identifying compounds in mechanical and electronic environments, see National Research Council Committee on Modern Methods of Handling Chemical Information, *Survey of Chemical Notation Systems: A Report* (Washington, DC: National Academy of Sciences, 1964).

[89] Verkade, *A History*, 8, 51. The English translation, not cited by Verkade, is "Resolutions Adopted by the International Commission," *Chemical News* 65 (1892): 277–80.

[90] Beilstein to Fischer, 4/16 Oct 1892, in Elena Roussanova, ed., *Friedrich Konrad Beilstein, Chemiker zweier Nationen*, vol. 2 (Hamburg: Books on Demand, 2007), 405–7.

[91] Béhal, "Nomenclature Chimique," 411; Armstrong, "International Conference," 57–58.

[92] C. I. Istrati, *Curs Elementar de Chimie* (Bucharest: C. Göbl, 1893). Friedel arranged for the publication of a French edition and wrote a preface for the translation; Constantin I. Istrati, *Cours Élémentaire de Chimie*, trans. Alphonse Adam (Paris: G. Carré, 1895).

> The rational index-nomenclature must, in order to avoid arbitrariness, treat all compounds as equals, as the citizens of a socialist State would be treated. The [non-index] text-nomenclature—corresponding to our existing social order—raises out from the great masses certain compounds to which fate or merit has assigned a 'role.'[93]

With the accumulation of more and more rules, and more and more official names indistinguishable to those without special training in nomenclature, these editors worried that fewer and fewer chemists would be capable of using the chemical literature effectively: "Such a state of affairs—a separation of chemists into index-educated scholars and index-ignorant technicians—would be highly undesirable and would contradict the traditions of our science."[94] The radical *egalité* that the Geneva nomenclature imposed upon the metaphorical polity of organic substances would, feared the editors of the *Berichte*, bring about a real division within the social order of chemistry.

They were not entirely wrong. On the one hand, by enshrining the late nineteenth-century structural formula as the basis of chemical names, the Geneva Congress helped establish the status of these diagrams as the "iconic vernacular" of chemistry.[95] On the other, the Congress also launched the study of methods for "official" nomenclature as a separate channel of research running parallel to the chemical mainstream. As the size of the chemical world and the complexity of compounds increased, systematic nomenclature grew ever more esoteric and ever more vital. Within international commissions, chemical publications enterprises, manufacturers' laboratories, and elsewhere, chemists continued to chase the elusive goal set at Geneva: generating systematic names—or machine-readable ciphers, or digital tables—that represent compounds just as the structural formula does.

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[93] Paul Jacobson and Robert Stelzner, "Zur Frage der Benennung und Registrirung der organischen Verbindungen," *Berichte der Deutschen Chemischen Gesellschaft* 31 (1898): 3372.

[94] Jacobson and Stelzner, "Zur Frage," 3375.

[95] Hoffmann and Laszlo, "Representation in Chemistry," 176.

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