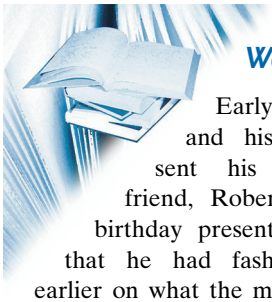


From the Molecular World

Early in 1882, the chemist and historian Hermann Kopp sent his distinguished chemist friend, Robert Bunsen, a whimsical birthday present: a speculative fantasy that he had fashioned some six years earlier on what the micro-world of atoms and molecules might be like. It was a spin-off of a much more ambitious but never-completed project to analyze the previous quarter-century's developments in chemical theory. He also sent copies to a small number of prominent chemists, all friends of his. The fantasy was published anonymously later in the year (possibly at the instigation of Kekulé) under the title, *Aus der Molecular-Welt*. There followed a second and, four years later, third printing (1886), in which both the author and the dedicatee were finally named.

Alan Rocke's first book, *Chemical Atomism in the Nineteenth Century: From Dalton to Cannizzaro* (1984) has become the classic history of the development of the chemical atomic theory. Recently, he published something of a sequel to Chemical Atomism: a history of the development of structural chemistry under the title *Image and Reality: Kekulé, Kopp and the Scientific Imagination*. One review of this book, by Jeremiah James, was itself titled, "Imagining the Invisible",[1] and, indeed, the principal theme of this book is the study of the creative imaginations of chemists in their move from the laboratory bench of chemical reactions to the micro-order of atoms in molecules. Also, as the subtitle indicates, Hermann Kopp was already one of the protagonists and there is an extended account of *Aus der Molecular-Welt*.[2]

Rocke has now published a scholarly translation of this work, with an introduction that sets it in historical context through a brief but meaty scientific biography of Kopp, and with fascinating scholarly footnotes. I shall begin my own discussion by presenting the "flavor" of the fantasy and of Rocke's edition of it by means of an excerpt giving the formation and behavior of water molecules, along with one of Rocke's footnotes:

"A two-handed oxygen atom and two one-handed hydrogen atoms are associated together: the oxygen atom holds the hand of a hydrogen atom with each of its two hands. As far as it can, the molecule rushes straight ahead, while each of the three atoms belonging to it performs in addition the motions characteristic to them. The *allemande á trois* is performed in a charmingly beautiful way, nearly as beautiful as it was danced in our youth by the then-famous Alexander Casorti with his two sisters, (footnote) where also it was particularly the intermolecular movements of the dancers that were so appealing."

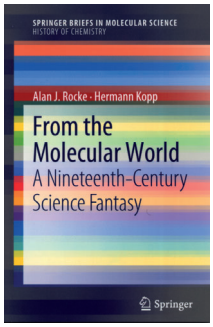
Rocke's footnote to these dancers:

"*Allemande á trois getanzt von Alexander[u. seinen Schwestern] Therese und Victorine Casorti, für Pianoforte zu 2 und 4 Handen* (ca. 1830), in the Staatsbibliothek zu Berlin. I was able to locate no better or fuller references to Alexander Casorti and his sisters."[3]

As the anthropomorphism in the quotation makes clear, Kopp's exploration of the world of atoms and molecules is certainly not meant to be epistemologically "literal"; yet neither is it merely fantastical. The theoretical understanding of the atomic constitution and behavior of the water molecules is conveyed—and conveyed humorously—through their transmutation into human action. This is the pattern of the entire fantasy.

In his biographical Introduction, Rocke delineates a philosophically and scientifically complex career for Kopp. Philosophically, Kopp had to grapple with contradictory impulses within him: on the one hand, an inductivist, a-theoretical impulse (in line with many of his contemporaries in mid-nineteenth century, some under the influence of the ascendant positivist philosophy); on the other, a theoretical impulse, expressed through his search for scientific means to "see, with the mind's eye, the hidden world of atoms and molecules and to do so with epistemological confidence."[4] Scientifically, Kopp implemented this latter impulse in his own scientific research by concentrating on the determination of physical characteristics of material substances: crystal forms, densities, specific heats, boiling points, volumetric changes etc., which he thought to be a more reliable way than chemical properties to lead the "mind's eye" to theoretical comprehension of the atomic-molecular microworld. By pursuing this course of research, Kopp "bet on the wrong horse" in Rocke's words.[5] It was chemical properties and relations of organic compounds that spurred the great theoretical advances towards structural chemistry in the later nineteenth century, something Kopp himself came to appreciate.

In *From the Molecular World*, Kopp gave a survey of much of the domain of chemical interests from the atomic-molecular viewpoint. In addition to the atomic-molecular anthropomorphism already noted, human presence was also manifest in the point of departure for the presentation of the components of the survey: the Naples aquarium, completed in 1874 and already a major tourist and research site in Europe. It was a personally as well as scientifically appropriate venue because Bunsen and his friend, the physicist Georg Quincke, were in Italy and were expected to be in Naples on Bunsen's birthday. Corresponding to the aquarium with its rooms with individual displays of diverse



From the Molecular World A Nineteenth-Century Science Fantasy. Springer-Briefs in History of Chemistry Series. By Alan J. Rocke. Springer, 2012. 105 pp., softcover, 53.45 €.—ISBN 978-3642274152

aquatic creatures was Kopp's *aerarium*. This, too, had separate exhibits for displaying different chemical denizens. As this neologism is presumably meant to imply,[6] the first set of exhibits (in glass balloons) was devoted to gases. As the earlier quote on water molecules stated, Kopp's atoms were endowed with "hands", which corresponded to the valence of the atomic species.

In the first section, the exhibits in the *aerarium* displayed the major elemental gases: hydrogen, chlorine, oxygen and nitrogen. Since the molecules of each of these gases are diatomic and the component atomic species differ in their "handedness", the molecules were formed by the mutual clasping of one, two or three (in the case of nitrogen) hands. Kopp did note that oxygen can form a mutual one-handed clasp between three atoms to form ozone. The anthropomorphic "cause" of bonding between gaseous atoms of the same species Kopp called "friendship". The counter-example case of mercury vapor—single atoms even though mercury is divalent—lead to another anthropomorphized explanation:

"Not one offers a hand to another to follow their zigzag path together as a couple; rather, at each of the perpetual meetings and collisions, each grumbles to the other: 'I will not extend my hand to you as a friend, and will not be your brother.' So with respect to the satisfaction of the aforementioned trait [friendship for the diatomic gaseous molecules], what does a mercury atom do … ? Nothing is simpler: he holds one of his own hands with the other." [7]

Combination between atoms of different chemical species was distinguished from "friendship" as "affinity" and metaphorically related to human marriage. Here, Kopp displayed his humor in the example of the union of hydrogen and chlorine atoms to form "chlorine hydride":

"After a while we catch sight of the couple and ask ourselves whether these two have found that enduring inner bliss in their combination which matches the fire with which the union was sealed. Unfortunately we cannot be as convinced of this as we would like to be; the couple appears to be desperately sour, and the cowering hydrogen looks as if he is thinking, 'Affinity, oh affinity has brought me to this state.'" [8]

Not only chemical composition but also physical properties of the gases were explored, e.g. molecular motion, diffusion etc.

In the next section of the work, Kopp dropped the Naples aquarium metaphor in order to make an excursus into more theoretical chemical matters: how do more complex molecules than the simple binary gaseous ones form, particularly for carbon-based compounds? Here, Kopp set forth two competing approaches (without naming their progenitors), which, he asserted, "exist in open warfare" even if they have "much in common":[9] They were, in fact, the approaches of Hermann Kolbe and Friedrich August Kekulé, often characterized respectively as the "radical" and the "structural" approaches. In his anthropomorphic perspective, Kopp characterizes the first as positing "the inequality of dignity of materially similar atoms"; in contrast, in the second approach, "all materially similar atoms are equal in rank; in their behavior they are unequal only according to what is united most closely with them." [10] Kolbe detested the approach of Kekulé but he was a friend of Kopp. Diplomatically, Kopp delineated both approaches as "only fictions [which] cannot claim the glory of teaching us how it really is in nature" but as also having "much in common".[11]

All this was prelude to the next section, which dealt with organic chemistry. The narrative returned to the venue of the *aerarium* and the glass balloons, now filled with organic compounds such as "wood alcohol" (methanol), formic and acetic acid [in a new room called the *Caldario*], and "benzol" (benzene) in yet another room named *Compartimento Aromatico*. Kopp described anthropomorphically Kekulé ring structure, comparing it to the children's dance, "Ring Around the Rosie". In order no doubt to placate Kolbe after this enthusiasm, Kopp, once again, felt the need to strike a neutral pose between the two approaches.

The following section, devoted to organic radicals,[12] displayed Kopp's—and presumably Bunsen's—political orientation. He castigated some radicals, particularly those with uneven numbers of "hands", as "not managing their affairs as adherents of liberal politics", with one-handed ones as "among the worst of their kind", because of their aggressive, "very sly", reactivity. The cyanide radical (CN) was his principal example and Kopp noted the poisonous results of its aggression.[13] By contrast Kopp praised gaseous "molecular states" (gaseous kinetics) as "democratic on the broadest foundation":

"As a matter of principle, no atom enjoys a preferred place above any other; nothing is known of rights of birth or of class … .In every state, even those with a mixed population—where molecules of unequal weight are assembled together—an equal *vis viva* [kinetic energy] is assured for all molecules. The organism of the state functions without any special official authority." [14]

I focus on the social and political allusions and metaphors because they are naturally of the highest interest to historians—historians of science included. The scientific content is also of great interest to the historian of science. Since Kopp was quite inclusive in his account of chemical theory and was himself a preeminent historian of chemistry, *From the Molecular World* provides a very useful overview of the theoretical "state-of-the-art"

of chemistry in the early 1880s. For example, as Rocke notes in his footnote commentary, Kopp's discussion of electrolysis preceded by just a few years the publication of Arrhenius' theory of electrolytic dissociation; hence, Kopp made no mention of charged ions in solution in his account.

The closest work that I could think of to Kopp's imaginary (and imaginative) tour of the micro-world of atoms and molecules was a nearly contemporary work that has since maintained its presence in the literary-scientific canon: *Flatland: A Romance of Many Dimensions* by Edwin A. Abbot (1884).[15] As is well known, Flatland described an inhabited world of two dimensions. Like Kopp's atomic and molecular denizens, Abbot's two-dimensional geometrical inhabitants are invested with social and political characteristics; even more than *From the Molecular World*, *Flatland* is intended to be a social satire. It has maintained its place, however, mainly for its mathematical-scientific cachet, especially in the light of the Theory of Relativity, in which we three-dimensional denizens live (and have to cope at least in theory) with a four-dimensional world.

From the Molecular World is more rooted, I think, in the nineteenth century. Certainly, scientifically, it is difficult for me to imagine what a "mind's eye" might image of a post-quantum chemical micro-world (although the effort might be worth trying). Although Kopp's anthropomorphic embroidery of atoms and molecules was not meant to be taken seriously, there was still some sense that the micro-world was not necessary qualitatively different from the actual world of our senses. That, of course, changed radically in the twentieth century.

Moreover, the anthropomorphism does give the work an endearingly nostalgic flavor of the pre-World War I European world. It is an optimistic view, both scientifically and, I dare say, politically and socially. It is also a view that valued and privileged European civilization above all others. At the very end, Kopp asserted this openly, when discussing—of all things—hydrated salts in solution:

"What would be the simplest thing, and what would correspond to the arrangements of the races of mankind that are more inclined toward higher civilization, would be to assume that each single molecule of one kind might unite molecularly with a single molecule of the other kind. But according to recent views, the processes of dissociation in solution of hydrated salts are truly Turkish, which suggests that to one molecule of salt several molecules of water are present."[16]

Fifty years after *From the Molecular World* was published, this relatively harmless European ethnocentrism of Kopp was poised to be transmuted into the virulent, lethal racism of Nazi Germany. Just as quantum mechanics had made the chemical micro-world into a strange and difficult-to-visualize domain, so World War I and its aftermath had destroyed the social and political optimism that permeated Kopp's fantasy. In our own age of bewilderingly rapid social, economic, scientific technological change, it is comforting to read and savor Kopp's molecular fantasy.

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DOI: 10.1002/anie.201210305

[1] *American Scientist* **2010**, *98*, 500.
[2] *Image and Reality: Kekulé, Kopp, and the Scientific Imagination,* Alan J. Rocke, The University of Chicago Press, **2010**, pp. 268–281.
[3] *From the Molecular World. A Nineteenth-Century Science Fantasy*, Alan J. Rocke, Springer, **2012**, p. 42 (footnote 47).
[4] Ref. [3], p. 11.
[5] Ref. [3], p. 23.
[6] As Rocke notes in a footnote, this was the word for the ancient Roman "treasury" so a double entendre may be intended.
[7] Ref. [3], p. 39.
[8] Ref. [3], pp. 41–42.
[9] Ref. [3], p. 47.
[10] Ref. [3], p. 45.
[11] Ref. [3], p. 52.
[12] Defined here as "parts or pieces of a compounds which, separated from that with which they were earlier united, and united with different things to form compounds, communicate a common behavior to all the compounds in which they enter, especially the ability to bring forth one and the same characteristic substance." Ref. [3], p. 59. Common examples are the methyl and ethyl radicals.
[13] Ref. [3], pp. 59–61.
[14] Ref. [3], p. 79. Rocke notes the double entendres in Kopp's use of German terms to characterize both political and material "states" and "constitutions".
[15] *Flatland: A Romance of Many Dimensions*, Edwin A. Abbot, Seeley and Co., London, **1884**.
[16] Ref. [3], p. 103. Kopp was, of course, contrasting marriage customs: monogamy of the "higher civilization" (European) with polygamy of Turkish (Islamic) civilization.