BOOKS & ARTS

Chemistry's visual origins

Vivid imagination was key to unlocking the secrets of molecular structure in the nineteenth century, finds **Andrew Robinson**.

Image and Reality: Kekulé, Kopp, and the Scientific Imagination
by Alan J. Rocke
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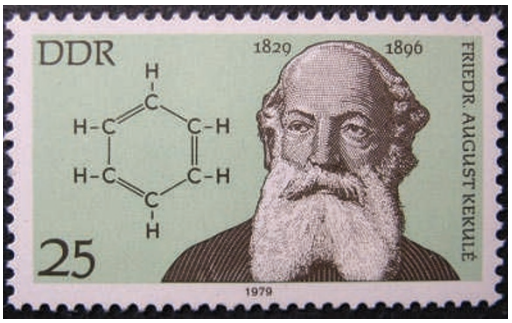
Most organic chemical compounds contain loops of six carbon atoms called benzene rings. The nineteenth-century German chemist August Kekulé claimed to have pictured the ring structure of benzene after dreaming of a snake eating its own tail. In *Image and Reality*, Alan Rocke offers a definitive account of Kekulé's life and the significance of visualization in the development of chemistry.

The scientific understanding of benzene was of crucial importance. Isolated as a liquid from compressed coal gas by Michael Faraday in 1825, it was used to make the first synthetic dye, mauveine, from aniline (aminobenzene) in 1856. In 1865, Kekulé proposed that benzene's structure was a hexagonal ring of six tetravalent carbon atoms, each able to form four bonds: one to a hydrogen atom and the others to adjacent carbon atoms. This concept — foreseen by him as "an inexhaustible treasure-trove" — was rapidly accepted by organic chemists because it predicted the existence of many benzene derivatives that were quickly synthesized in the laboratory.

Some historians have suggested that Kekulé stole the credit for discovering benzene's structure from his contemporaries, notably the Scottish chemist Archibald Couper and Austrian scientist Josef Loschmidt, by fabricating a story of two daydreams he had about whirling carbon atoms forming chains, "twisting and turning like snakes". In a 1985 paper, Rocke offered a brilliant refutation of these allegations. Using archival evidence, he argued that the concept of carbon tetravalency and the benzene ring developed cautiously and logically in Kekulé's mind during 1854–65. The two daydreams were integral episodes: the first in the summer of 1855 on top of a London omnibus, the second in 1862 in his apartment in Ghent, Belgium, while Kekulé was writing a pioneering chemistry textbook.

In *Image and Reality*, Rocke covers Kekulé's work, varied life and personality, and locates the chemist's thinking in the context of developing ideas about chemical bonding and molecular structure. After the beginnings of John Dalton's atomic theory in the early 1800s and the discovery of electrolysis, Swedish chemist Jacob Berzelius suggested that chemical bonding resulted from electrical attraction between oppositely charged components. Although this worked well for inorganic compounds such as sodium chloride, it was inadequate for organic compounds, in which electrochemically positive hydrogen could be replaced by negative chlorine with minimal alteration of the compound's chemical or physical properties.



German chemist August Kekulé visualized the ring structure of benzene in 1865.

The observation of simple ratios of elements in organic molecules then led to the concept of atomicity in the 1850s, later renamed as valency: hydrogen with a single bond to another element is monovalent, oxygen with two is divalent, nitrogen with three is trivalent and carbon with four bonds is tetravalent. The study of the spatial arrangement of atoms in molecules, or stereochemistry, was established in the 1880s by the Dutchman Jacobus Van't Hoff, the first Nobel laureate in chemistry.

The book includes a large cast of scientists, often at loggerheads, who worked mainly in Germany, France and Britain. A chapter is devoted to German chemist Hermann Kolbe, a firm believer in Berzelius's electrochemical dualism and a vitriolic critic of structural formulae for molecules. Kolbe attacked Kekulé's "wild fantasies without any real basis", and dismissed Van't Hoff as "fit for the madhouse". Another chapter focuses on Hermann Kopp, a German chemist–historian, teacher and friend of Kekulé, who in 1886 published an ingenious fantasy about the micro-world, *Aus der Molecular-Welt* (*From the World of Molecules*). This playfully advocated the importance of the imagination in devising molecular structures — such as picturing carbon atoms dancing 'Ring around the rosie' in benzene — and was respectfully referred to by Kekulé and other chemists.

Rocke's thesis is that "human minds work far more visually, and less purely linguistically, than we realize." At every turning point, he suggests, early chemists used their imagination to visualize the constitution of the micro-world, leading the way in visual thinking. Van't Hoff, for instance, constructed simple but vital cardboard tetrahedral models of carbon atoms and their bonds, which he sent to chemists across Europe. After 1857, physicists such as Faraday, James Clerk Maxwell, Hermann von Helmholtz and Ludwig Boltzmann followed, developing the kinetic theory of gases and heat on the basis of a vision of dynamic atoms and molecules.

Kekulé championed visual scientific creativity. Speaking in 1890 at a meeting held in his honour — when he first went on record with his dream anecdotes — he attributed his success to his eclectic and international education, his obsessive hard work and the pictorial nature of his mind. He had what he called an "irresistible need for visualization" (*Anschaulichkeit* in German), perhaps engendered by his architectural training in the 1840s before he switched to chemistry.

Even so, as Rocke concedes, Kekulé's attempt at a visual notation for the benzene ring was unsuccessful. He depicted the carbon atom as a sausage with four single bonds along its length, which required awkward manipulation to form a symmetrical ring. Kekulé abandoned the sausages in 1867 in favour of a graphic formula closer to the modern 'ball-and-stick' depictions, which derive from the work of Scottish chemist Alexander Crum Brown.

Such visualization of the micro-world is now commonplace. Yet the role of visual thinking in the scientific mind is not universally accepted. "For scientists, mental images may seem downright embarrassing," suggests Rocke. But for Kekulé, as this subtle and penetrating study shows, dream images translated into chemical reality. ■

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