Chemistry in Space,
1874-1914

From Structural Formulas as Symbols to Structural Formulas as Icons.
The Meaning of Structural Formulas, circa 1874

[These formulas are] used to express constitutional formulae, and by which, it is scarcely necessary to remark, I do not mean to indicate the physical, but merely the chemical position of the atoms. ... and while it is no doubt liable, when not explained, to be mistaken for a representation of the physical position of the atoms, this misunderstanding can easily be prevented. (Alexander Crum Brown, 1864)

Symbols: Signs that do not resemble the objects they represent.
Icons: Signs that do resemble the objects they represent.

Chemistry in space: The conversion of structural formulas as symbols into structural formulas as icons.
I. Optical Activity and Organic Chemistry

Jean-Baptiste Biot (1774-1862)

- 1815: solutions of some organic compounds are optically active
- Correlation between sample length, wavelength and magnitude of rotation
- 1830s: Standardized polarimetric techniques
- Saw great theoretical and practical value for optical activity
Louis Pasteur (1822-1895)
Pasteur and Salts of Tartaric Acid

- Student of Auguste Laurent
- Relationship between optical activity and crystalline form of tartaric and paratartaric acid (isomers)
- Eilhard Mitserlich, 1844
  - sodium-ammonium salts of tartaric and paratartaric acid had identical crystalline forms
  - tartrate solution optically active
  - paratartrate is optically inactive
  - Why isn’t this reflected in crystalline form?
- Upon forming these salts, Pasteur noticed
  - tartaric acid crystal were hemihedral and asymmetric
  - paratartaric acid crystals were hemihedral but a mixture of enantiomeric forms.
Figure 2. Hemihedral crystals of sodium ammonium tartrate (Pasteur).

Figure 7. Sodium ammonium tartrate. (left) l or (−) form. (right) d or (+) form. (bottom) racemate (+)(−) form.
Johannes Wislicenus (1835-1902)
Wislicenus’ formulas for lactic acid, 1863

Acidic nature

Alcoholic nature
Ethylidene lactic acid (α-hydroxypropionic acid)

Ethylene lactic acid (β-hydroxypropionic acid)
Such finer cases of isomerism would probably be interpreted by
spatial conception concerning the grouping of atoms, that is, by
model formulas.

Wislicenus, September 1869

Facts like these will force us to explain the difference of
isomeric molecules of equivalent structure by different positions
of their atoms in space, and to look for possible ideas about
these positions. Possibly an exact determination of the density
of the modifications of lactic acid will bring to light a difference
in the spatial materialization of molecules (*molekülare
Raumerfüllung*), perhaps such that the optically active meat
lactic acid, which the lecturer considers a modification of
ethyldene lactic acid … does not contain the atoms arranged
together in the smallest possible space.

Wislicenus, November 1869
Lactic Acid Isomers, 1873

- Ethylene lactic acid--artificially prepared, optically inactive
- Paralactic acid--from meat extract, optically active
- Fermentation lactic acid--from milk, optically inactive
- Hydracrylic acid--artificial, optically inactive.

- Paralactic acid and Fermentation lactic acid were both ethylidene lactic acids (2-hydroxypropionic acid).
That the chemical properties of a molecule are most decisively \([am\ Entschiedensten]\) determined by the nature of the atoms that compose it and by the sequence of their mutual combination, the chemical structure of the molecule, is now a generally shared conviction. No less justified, it appears to me, is the assumption that differences in the geometrical arrangement of chemically structurally identical molecules, that can primarily give rise to deviations in the molecule’s size and form, must above all also become noticeable in physical properties, among which could quite possibly be included certain differences in those properties lying on the border areas of physical and chemical relationships, such as solubility, crystal form, water of crystallization, and so forth.

II. The Tetrahedral Carbon Atom, 1874


J. H. van ‘t Hoff (1852-1911)
VOORSTEL TOT UITBREIDING

DER TEGENWOORDIG IN DE SCHEIKUNDE GEBrUIKTE

STRUCTUUR-FORMULES

IN DE RUIMTE:

RENEVENN EEN DAAMELIJ SAMENHANGENDE OPMERKING

OMTRENT HET VERBAND

TUSSEN

OPTISCH ACTIEF VERMogen

EN

CHEMISCHE CONSTITUTIE

 VAN

ORGANISCHE VERBINDINGEN.

Utrecht. — J. Greven. — 1874.
If one assumes that these atoms [bound to carbon] are extended in a plane, ... in applying this assumption to the derivatives of methane CH4 (to start with the simplest case), one arrives at the following number of isomers ...

One for CH₃R¹ and for CH(R¹)₃

Two for CH₂(R¹)₂, for CH₂(R¹R²) and for CH(R¹)₂R²

Three for CH(R¹R²R³) and for C(R¹R²R³R⁴), which is evidently a much greater number than those known so far

A second assumption brings theory and fact into agreement, that is, by imagining the affinities of the carbon atom directed towards the corners of a tetrahedron whose central point is the atom itself. The number of isomers then simply reduces to:

One for CH\textsubscript{3}R\textsuperscript{1}, CH\textsubscript{2}(R\textsuperscript{1})\textsubscript{2}, CH(R\textsuperscript{1}R\textsuperscript{2}), CH(R\textsuperscript{1})\textsubscript{3} and CH(R\textsuperscript{1})\textsubscript{2}R\textsuperscript{2}; but two for CH(R\textsuperscript{1}R\textsuperscript{2}R\textsuperscript{3}), or more generally for C(R\textsuperscript{1}R\textsuperscript{2}R\textsuperscript{3}R\textsuperscript{4}); ... in other words: in cases where the four affinities of the carbon atom are saturated with four mutually different univalent groups, two and not more than two different tetrahedra can be formed, which are each other’s mirror images, but which cannot ever be imagined as covering each other, that is, we are faced with two isomeric structural formulas in space. ...
LA CHIMIE DANS L'ESPACE

PAR

J. H. VAN 'T HOFF (M. A. C.)

Docteur ès sciences.

Die Thatsachen zwingen dazu die Verschiedenheit isomerer Moleküle von gleicher Strukturformel durch verschiedene Lagerung ihrer Atome im Raum zu erklären.

WIRKLICHKEIT.

ROTTERDAM.

P. M. BAZENDIJK.

1875.
Paper models of the asymmetric carbon atom, made by van't Hoff and sent to his friend G. J. W. Bremer on July 13, 1875. (Courtesy Rijksmuseum voor de Geschiedenis der Natuurwetenschappen, Leyden)
Recipients of *La chimie dans l’espace*

- Adolph von Baeyer (Munich)
- Marcelin Berthelot (Paris)
- Aleksandr Butlerov (Kazan)
- Edward Frankland (London)
- August Wilhelm von Hofmann (Berlin)
- August Kekulé (Bonn)
- Adolphe Wurtz (Paris)
- Johannes Wislicenus (Würzburg)
Johannes Wislicenus (1835-1902)
DIE LAGERUNG DER ATOME
IM RAUME

VON

Dr. J. H. VAN 'T HOFF.

Nach des Verfassers Broschüre „La chimie dans l'espace“
deutsch bearbeitet

VON

Dr. F. HERRMANN,
Assistenten am landwirtschaftlichen Instituto der Universität zu Heidelberg.

Nebst einem Vorwort

VON

Dr. JOHANNES WISLICENUS,
Professor der Chemie an der Universität zu Würzburg.

MIT IN DEN TEXT EINGEDRUCKTEN HOLZSTICHEN.

BRAUNSCHWEIG,
DRUCK UND VERLAG VON FRIEDRICH VIEWEG UND SOHN.
1877.
III. The Stereochemistry of Nitrogen

Alfred Werner           Arthur Hantzsch
I. Es können also den beiden stereochemisch isomeren Kohlenstoffverbindungen der Form $XY: C = (CH)Z$

\[ \begin{array}{c}
X \\
\sqrt{}/
\end{array} \begin{array}{c}
Y \\
\sqrt{}/
\end{array} \quad \text{und} \quad \begin{array}{c}
X \\
\sqrt{}/
\end{array} \begin{array}{c}
Y \\
\sqrt{}/
\end{array}
\]

und

\[ \begin{array}{c}
H \\
\sqrt{}/
\end{array} \begin{array}{c}
Z \\
\sqrt{}/
\end{array} \quad \text{und} \quad \begin{array}{c}
Z \\
\sqrt{}/
\end{array} \begin{array}{c}
H \\
\sqrt{}/
\end{array}
\]

zwei stereochemisch isomere Kohlenstoffverbindungen von der Form $XY: C = (N)Z$ entsprechen:

\[ \begin{array}{c}
X \\
\sqrt{}/
\end{array} \begin{array}{c}
Y \\
\sqrt{}/
\end{array} \quad \text{und} \quad \begin{array}{c}
X \\
\sqrt{}/
\end{array} \begin{array}{c}
Y \\
\sqrt{}/
\end{array}
\]

\[ \begin{array}{c}
N \\
\sqrt{}/
\end{array} \begin{array}{c}
Z \\
\sqrt{}/
\end{array} \quad \text{und} \quad \begin{array}{c}
Z \\
\sqrt{}/
\end{array} \begin{array}{c}
N \\
\sqrt{}/
\end{array}
\]

Stereoisomeric Benzildioximes (modern notation)
IV. Carbohydrate Chemistry

• What is the structure of glucose?
• How should we classify the sugars?
• 1889: concluded that mannose and glucose had the same structure.
• van ’t Hoff’s theory as a guide for unravelling the relationships between the natural and artificial isomeric monosaccharides.
• Sixteen possible stereoisomers, following van ’t Hoff’s 2^n rule.

Emil Fischer (1852-1919)
... modern configurational formulas proclaim with the clarity and brevity of a mathematical expression both the already established metamorphoses of the simple sugars and the many still to be expected, and one may indeed say that at the moment, the morphology and systematics of the monosaccharides has been achieved.

Emil Fischer. “Die Chemie der Kohlenhydrate und ihre Bedeutung für die Physiologie,” (1894)
V. Inorganic Stereochemistry

Alfred Werner (1866-1919)
1) metal atoms can act as central atoms of stable, asymmetrically constructed molecules and thereby lead to phenomena which agree with those produced by the asymmetric carbon atom;

2) offering the proof that pure molecular compounds can also occur as stable mirror image isomers, whereby the difference between valence compounds and molecular compounds, which is still frequently maintained, disappears entirely, and

3) the confirmation of one of the most far-reaching conclusions from the octahedral formula, by which the latter has found a new and important support.

Further Reading