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BY WAY OF EXPLANATION

Otto Theodor Benfey, Chemical Heritage Foundation

When I began contemplating early retirement from Guilford, I expected to fade quietly into the background from the world of activity and achievement. I never expected the recognition given me, including the plans for this symposium, Arnold Thackray's invitation to join him at the Beckman Center for the History of Chemistry, and with it a most satisfying faculty linkage with the University of Pennsylvania's Department of the History and Sociology of Science. Now I am again savoring the delights of being an editor - periodically seeing a mass of jumbled notes, manuscripts and pictures being miraculously transformed by my excellent production staff, led by Frances Kohler, into a pleasing product.

Not often does a group of academic and industrial research chemists and educators, historians and government officials participate in the same gathering. Yet such a group was gathered in Winston-Salem at the ACS Southeast Regional Meeting. Its diversity is a reflection of the motley jumble in my brain. Until a few weeks ago I could find little to justify my various enthusiasms, there seemed little to link them together. What could possibly unite my interest in Plato's *Timaeus*, the Newton-Leibniz particle-monad controversy (in which my sympathies were all on Leibniz's side), structural organic chemistry, chemical education, the Orient, the Society for Social Responsibility in Science, my fascination with the five regular solids - the tetrahedron, octahedron and so on - and searching for scientifically meaningful and sound definitions of common yet not clearly understood chemical concepts?

Three weeks ago in a most unexpected place I found the link - rereading after several decades Nicholas Berdyaev, the Russian religious philosopher (1):

> The natural world, according to the Aristotelian and Thomist conception, is not penetrated by divine forces; it lives according to its own laws and is only subject to the organized action of external grace.

He contrasts this with the Platonic view in which (1):

> The natural is rooted and grounded in the supernatural; the divine energy comes into the world and makes it divine. The empirical world is rooted in the world of ideas and the world of ideas rests upon God.

I have discovered that I am hopelessly anti-hierarchic, objecting strongly to the notion that the material is fundamentally different from and inferior to the spiritual. I am, it seems, a neo-Platonist, seeing, and if not seeing then passionately searching for divine perfection, that of God, as Quakers would say, in my fellow human beings and in the world of nature. I am fascinated by harmony, mathematical pattern and geometric form in chemistry and long to share my fascination with students and with a wider public via the printed word.

The unity of all creation, that pervasive interconnectedness, is stressed in Oriental thought. It characterized Leibniz's monads which seek to harmonize with each other, in contrast to Newton's isolated lonely billiard-ball atoms that needed superior guidance to dragoon them into acceptable behavior.

There was an occasion some years ago when I made an attempt to make a virtue of my dilettantism. In speaking to a group of high school teachers at a Dreyfus-Woodrow Wilson summer institute held at Princeton University, I called on them - as a way of preserving their intellectual sanity and their belief in their mission as teachers - to find some topic that interested them and to pursue it whenever an opportunity presented itself and wherever it led.

My personal topic of fascination had been the regular geometric (Platonic) solids, the tetrahedron, octahedron, icosahedron, dodecahedron, and cube, from which Plato in his *Timaeus* constructs the world. I learned of Plato's *Timaeus* in the early 1950s from the German nuclear astrophysicist-philosopher Carl Friedrich von Weizsäcker in a conversation whose focus was the social responsibility of the scientist. Strange that chemistry texts continue to equate ancient science with Aristotle - probably to show how superior we are. If freshman chemistry began with the *Timaeus*, how different it would be.

I have pursued the regular Platonic solids ever since that conversation. Geometry is the clue to understanding organic chemistry, maybe to all of chemistry, and its organizing power had lured me into chemistry. The Platonic solids led me from a tinker-toy-type construction set I had given my children, via an 8th-century spherical incense burner with dodecahedral design in Japan's imperial treasure house, to T'ang era China, to the pottery of Iran, to Malayan basket makers and Euclid's *Elements of Geometry*, via Kepler's spacing of the planets and the speculations of Couper, Kekulé, Le Bel, van't Hoff, and Alfred Werner, back to my field of structural organic chemistry and beyond it to the icosahedral geometry of the boron hydrides, intermetallic crystals and of tobacco mosaic and other viruses.

I suggested to my teacher audience that there is today a great need for lateral as well as longitudinal research - something like the distinction between external and internal history of science. In addition to the usual prescription for making one's mark in science by concentrating and specializing, learning, as some say, more and more about less and less, there is a need for the networkers too, those who show how all the specialized nuggets of expertise are interconnected. That, it seems to me, is the peculiar task of educators, to show the next generation the beauty and grandeur of the edifice of knowledge, in order to convince young people to participate in its construction and elaboration. Mendeleev acted in this manner when he was facing the task of organizing his new textbook. He sought for a rational basis for discussing the ever-growing list of elements - and found it in the periodic recurrence of chemical properties.

And similarly Kekulé's insight into the cyclic structure of benzene, with all that followed from it in the clarifying and rationalizing of aromatic chemistry. The rise and astonishing power of the organic-chemical and dye industries, arose, so Kekulé informs us, from a moment when his textbook writing did not progress and he dozed and daydreamed and saw the dancing atoms link up in a ring. It doesn't matter if, as some now contend, the atoms never danced and the dream never occurred. Be that as it may, no one so far has questioned Kekulé's claim that he was trying to write a coherent textbook and that "the work did not progress." He had this passion to connect fragments that he, maybe more than others, knew were fragments, that they belonged together if only he could find the key.

Here are two textbook writers, pedagogues, concerned, when engaged in that task, not so much to enlarge the frontiers of knowledge as to fashion a map that showed how the newly explored territories fitted with each other and with the old world. And in carrying out what seemed not at all a research task, they in fact immeasurably advanced the tempo and success-rate of research, not to mention the massive contribution to a country's gross national product.

I'd like to come back to my list of fascinations and comment on the last area, the clarification of chemical concepts. When I was a student at University College London, my professor, Christopher K. Ingold, gave a lecture on the optical activity and stereochemistry of certain substituted biphenyls. Their stability, their rates of racemization, depended markedly on the nature of groups in positions *ortho* to the interannular bond. Size did not seem a sufficient explanation. I went to the library and read some papers, something we had never been encouraged to do - reading the literature was not part of our training! I think I was even then aware that here was a form of stereoisomerism, of chirality, quite different from that enunciated by van't Hoff. For his type of isomerism, it was enough to examine the structural formula in terms of number of bonds and to what atoms they were attached. If four different groups radiated from a carbon, optical activity was expected and the number of isomers could be predicted with confidence.

In the case of the biphenyls there were no chiral centers - there were no carbons with four separate bonds to other atoms, and whether the molecule would be chiral or not could not be read from the formula. Biphenyl with two *ortho* carboxyl groups and two *ortho* nitro groups was chiral. If nitro groups were replaced by fluorines the molecule was not. To predict isomer number suddenly was no longer a task of simple arithmetic but required detailed physico-chemical knowledge of group sizes, kinetics and electronic effects on the interannular bond. There is a profound difference conceptually between van't Hoff's stereochemistry and that of the biphenyls, but in my 40 years of chemistry I have never seen mention of it in conceptual terms. My own writings on it have elicited no comments (2-4).

Thus my interest in chemical concepts surfaced in my student days in Europe, but they were powerfully reinforced by experiences in this country. I spent a postdoctoral year with Louis P. Hammett at Columbia in 1947 and was intrigued by Hammett and his mode of thinking. He had been influenced by Percy W. Bridgman's emphasis on operational definitions of every concept used in science. Hammett approached his own field of physical organic chemistry from that viewpoint. What, he would ask, operationally in terms of measurements performed, corresponded to resonance, to acid strength, to pH and so on. It was a field ripe for such analysis and Hammett did much to move the discussion of reaction mechanisms from speculation to an intellectually respectable area of research.

During that year I discovered George Willard Wheland's *Advanced Organic Chemistry*, a treasure trove of conceptual analysis, spending pages and pages on analyzing what we mean by isomer, while we "enlightened" teachers of the 1990s expect our students to understand isomerism as an obvious concept comprehensible after a brief description (5).

Where today do we find discussions of these and other basic concepts? They have largely vanished from our textbooks; it is in these grapplings that important new research problems will surface. However, some of the participants in this symposium are engaged in tasks of this kind. It is my hope that publication of this symposium will rekindle interest in such discussions, and will inspire some students to continue such lines of inquiry.

I want to return to my student days. The war years were years of intellectual as well as physical, material and political turmoil. Around me, among students and faculty, were intense discussions about the nature of science, its role and function in society, its future organization and direction. Some of the graduate students - even some among the faculty and staff - were members of the Communist Party. They were highly articulate and confident in their diagnosis of the ills of science and the way it had better be operated in the future. They exuded a remarkable confidence that they would be in charge after the war. It was extremely hard to argue with them successfully because they were consummate debaters and thoroughly prepared with facts and arguments. Yet some of us knew, deep down, that they were wrong. Their analyses of the ills of society and of the misuse of science were incisive and to a large degree valid. Their solutions for the future, however, were suspect. They were based on assumptions about the nature of human beings and the reasons for their behavior that I and others sensed to be plain wrong. They blamed all evil on the dominant exploiting class. They were utopian; with the right organization of society, humans would be good. They ignored the reality of sin, of self-centeredness and selfishness, and vastly overrated the ability of planners to know and implement what was good for society.

Their presence made some of us read intensively and grapple with the causative factors of science's historical development and with the responsibility of the scientist. And in the midst of this intellectual and other turmoil, on 6 August 1945, the atomic bomb was dropped on Hiroshima. I walked in a daze through the streets of London. A force of nature, whose power for destruction had been hinted at in our lectures, had been unleashed by a society I still believed was animated by ethical norms, against an unsuspecting country of a different race. All the criticisms of science and society were brought into focus and I had to subject my counter arguments to intensive scrutiny. Here were the highest intellectual capacities cooperating with government leaders to develop and utilize the high achievements of science for mass destruction and massive human suffering. Where now was Pasteur's confidence that science would in balance be used for human good?

I decided to drop science, to become a doctor maybe like Albert Schweitzer. But then I reconsidered and chose to continue my Ph.D. - but with a resolve to do what I could to help science serve the common good.

Around 1950 I was part of the early years of the Society for Social Responsibility in Science. I was delighted to read recently that both the head of DuPont and the editor of *The Scientist*, Eugene Garfield, one of our symposium speakers, were calling on scientists and on the chemical industry to pledge themselves to an ethic of social responsibility and environmental sensitivity. The way I put it is that, just as biologists are the guardians of the biosphere, so we of the chemical community must become the guardians of the lithosphere, the guardians and protectors of the material world.

My interests in the concepts and history of science and the role of science and scientists in society have remained intense ever since. Hence the title of this symposium: "The Context of Chemistry: Conceptual, Historical, Social".

References and Notes

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CORPUSCULAR ALCHEMY

The Transmutational Theory of Eirenaeus Philalethes

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Among the most influential works of 17th-century alchemy, the treatises attributed to "Eirenaeus Philalethes Cosmopolita" surely deserve a prominent place. As I have recently shown, several works attributed to this Philalethes were actually written by an American alchemist educated at Harvard, George Starkey (1). Starkey was born in 1628 in Bermuda, then considered part of "America." He entered Harvard College in 1643 and graduated with an A.B. in 1646. In 1650 Starkey immigrated to London, where he became a member of the scientific circle centered around Samuel Hartlib. In the early 1650s he performed a series of experiments with Robert Boyle, who was also a member of the Hartlib group. During this same period, Starkey wrote two works of major importance under the pseudonym of Eirenaeus Philalethes - the *Introitus apertus ad occlusum regis palatium* and the *Tractatus de metallorum metamorphosi*; both texts were published after Starkey's death during the great London plague of 1665.

The well-known Danish savant Olaus Borrichius reported posthumously in 1696 that Philalethes' *Introitus* was considered "by the whole family of chemists" to belong among "their classics" (2). Similar accolades had been uttered by Daniel George Morhof in his *Epistola ad Langelottum* of 1673 (3) and, to judge by the translations of the *Introitus* into English, German, French, and Spanish, and its numerous printings between 1667, when it first appeared in Amsterdam as the printing of Johann Lange, and 1779, it would seem that Philalethes' popularity was great indeed (4). Three further works by Philalethes, collectively named the *Tres tractatus*, were printed by Martin Birrius of Amsterdam in 1668 (5). In the following year the *Introitus* was translated into English and published as *Secrets Reveal'd* by William Cooper of London (6). Cooper became one of Philalethes' greatest promoters, publishing other *opuscula* by the alchemist whom he referred to in his *Philosophical Epitaph* as the "English phoenix." Cooper even advertised in the hope of discovering lost Philalethan manuscripts, promising to print whatever he could find (7).

Despite the almost frenzied interest in Philalethes during the Scientific Revolution, historians of science have been happy to ignore this alchemist until quite recently. Before the mid-1970s, virtually all the scholarship devoted to Philalethes had focused on the question of his identity, and most of this had been written by scholars in fields other than the history of science. Philalethes' alchemical writings have recently come to occupy an important place in the historiography of early modern science, however, thanks to the current interest in Isaac Newton's alchemy.

It is well known, of course, that Newton transcribed and composed a massive amount of alchemical literature, according to Richard Westfall's estimate over a million words (8). Those hardy few who have tried to ascertain the sources of Newton's alchemy, such as Westfall, Betty Jo Teeter Dobbs, and Karin Figala, agree in assigning an important role therein to Eirenaeus Philalethes (9). As a result of this discovery, virtually all serious analysis of the Philalethan *corpus* has been done by Newton scholars. Anyone who presently wishes to know what Philalethes thought will have to view his ideas through a Newtonian prism, which exercises its own peculiar refraction on our image of the American alchemist. It is my intention here to reconstruct the theory that lies behind the alchemy of Philalethes. In the course of this I shall make occasional reference to the recent work on Newton's alchemy, especially that of Figala. A judicious examination of Newton's debt to Philalethes will therefore serve both to illuminate some trends in Philalethan alchemy and to determine whether or not Newton's interpretation of it was in reality faithful.

De metallorum metamorphosi

Although the most famous of the Philalethan works is the *Introitus*, this work has more the character of an extended