TEACHING CHEMISTRY EMBEDDED IN HISTORY: REFLECTIONS ON C. K. INGOLD'S INFLUENCE AS HISTORIAN AND EDUCATOR

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History of Chemistry had always been associated in my mind with a few lectures by that title given by Christopher Kelk Ingold during my undergraduate years in the early 40's at University College, London, which through the exigencies of warfare were given in Aberystwyth, Wales. I remember them as deadly dull, early 19th century developments in understanding quantitative relations among reacting chemicals. I imagine the lectures covered material which I began to appreciate later when I came across Ida Freund's superb book, *The Study of Chemical Composition*(1). Ingold's handful of lectures of whose details I recall nothing gave me a permanent aversion to history of chemistry as a course topic. Even though I taught history of science in various forms over a 40-year period, I never taught a course entitled "history of chemistry" or remotely resembling such a name. The closest I came to it was a set of four lectures on the development of organic chemistry I gave to a CHF-Woodrow Wilson Foundation chemistry teacher group at Princeton in the summer of 1992.

Slowly my history of science courses incorporated one chemical topic after another as my own researches and fascinations with various phases of chemical history opened up those episodes. My main interests for long were in intellectual history, the development of ideas, particularly those of organic chemistry.

Those developmental sequences in organic theory also found their way into lectures for my organic chemistry students. In fact both in freshman chemistry and the majors course in organic chemistry I incorporated intellectual history – internalist history – whenever I was reasonably confident of my facts – and sometimes when I wasn't, when their anecdotal flavor was too delicious to ignore. It never occurred to me during those forty years to track to their source the developmental approach that was perhaps the most characteristic aspect of my teaching when compared with that of other college and university teachers in this country.

I began my teaching at Haverford College in January 1948, a year after coming to the States on a postdoctoral with Louis P.Hammett at Columbia. Hammett told me he was strongly influenced by Percy W. Bridgman to look at how scientific concepts were defined, what the operational definitions were for accurately understanding and employing those concepts and terms. The search for those definitions was an exercise in intellectual history, admittedly of a different sort. Hammett applied the approach to organic chemical practice and thereby created the extension of the pH concept to the Hammett acidity function H_0 because the operational definition of pH led to absurd values in highly acidic media. More broadly he was one of the pioneers of what we now know as physical organic chemistry.

At Haverford, my department head was William Buell Meldrum, a Harvard Ph.D. under T. W. Richards, who himself had been a Haverford graduate and at Harvard taught a course in history of chemistry. Meldrum had written what was considered an influential textbook, *Introduction to Theoretical Chemistry*(2), which dealt with many aspects of classical chemical theory – the concepts underlying our understanding of atomic weights and the periodic table – from a historical point of view (Fig. 1).

With Louis Hammett and William Meldrum as my chief American mentors, I may perhaps be forgiven if I

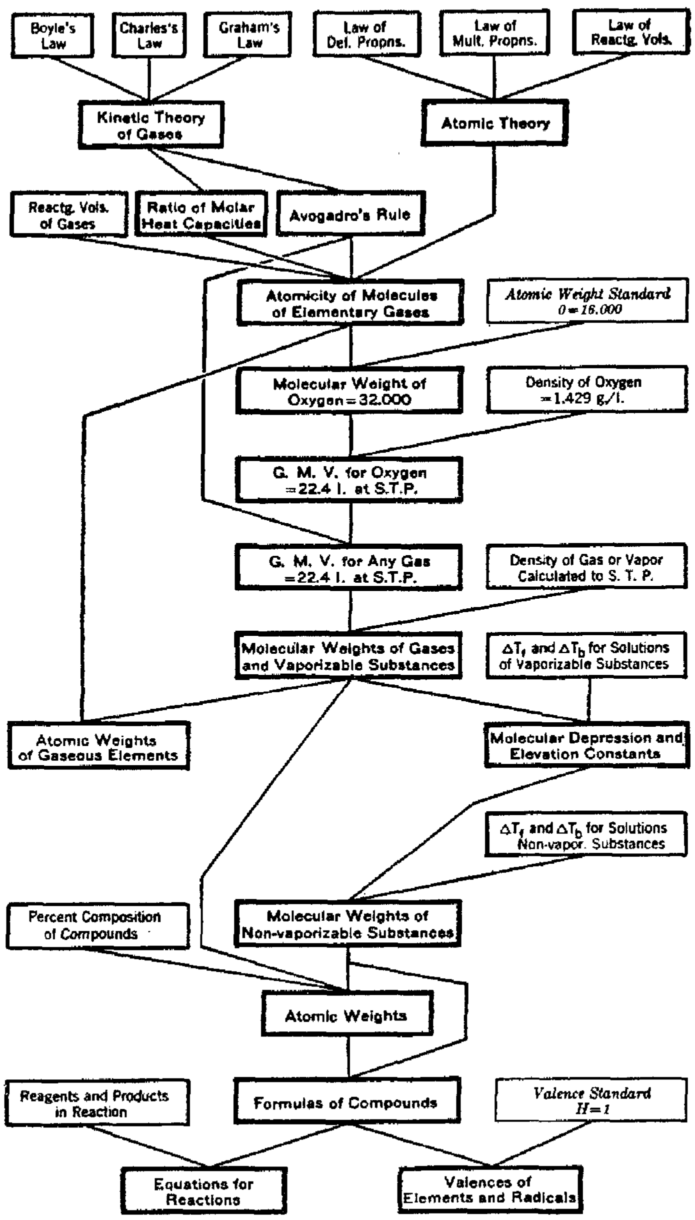

Figure 1 Fundamental Theory: Flowchart showing historical interactions leading to atomic weights, formulas, and equations. From William B. Meldrum and Frank T. Gucker Jr., *Introduction to Theoretical Chemistry* (2).

came to think that the accepted way to teach chemistry was as far as possible to present its current concepts in the context of their intellectual history.

That view was further strengthened by the case history approach to the sciences that James B. Conant introduced as a requirement for all nonscience majors when he returned to the Harvard presidency after his war service in Washington(3). He had been appalled to discover that legislators and government officials had scant understanding of how science worked, how discoveries were made. He decided that future decision makers needed to have such an understanding and that the way to do it was to teach key episodes of science in their historical context.

I attended Conant's summer school in 1949 where I met the Harvard teachers of the various courses that were carrying out Conant's vision—among them Leonard Nash, Thomas Kuhn, E. C. Kemble, and Gerald Holton. A number of the participants felt such courses should be required of science majors also. Out of that experience came my first foray into historical writing—a brief paper on William Prout and Prout's hypothesis. Several years later I worked with Leonard Nash and wrote my own organic chemical case study *From Vital Force to Structural Formulas*. Conant did not accept it for his series—it seems he had attempted to do the same himself and had decided it could not be done—but my manuscript was published by Houghton Mifflin (Harold Hart, series editor) and reprinted by the American Chemical Society and most recently by the Chemical Heritage Foundation(4).

Finally, I was fascinated by George Willard Wheland's *Advanced Organic Chemistry*(5), a more philosophical approach in which he devotes for instance forty pages to the clarification of the concept of isomer (before arriving at stereoisomers), a topic we expect our organic students to comprehend on the basis of one or two lectures. Wheland, a Conant Ph.D., had been a research fellow with Pauling at Pasadena from 1932 to 1936 and the following year had a Guggenheim Fellowship which he spent in England, with Ingold, as well as with N. V. Sidgwick and J. E. Lennard-Jones. William H. Brock in his *Norton History of Chemistry*(6) comments on the excitement generated by Wheland's book because he pointed to fundamental philosophical problems in chemistry.

Only six years ago, after I gave up teaching chemistry to devote myself wholly to its history, did it occur to me that the person from whom I learned my own approach to teaching was none other than C. K. Ingold (Fig. 2).

The lectures he prepared we copied essentially verbatim in our notes and memorized for that final comprehensive set of written examinations at the end of our undergraduate training, which determined whether we

Figure 2 University College London chemistry faculty and students after the return from Aberystwyth, 1945.

Left to right, front row: unknown, Elfred Evans, Dan Godard, Peter LaMer, "Butch" Easty, George Kohnstam, Alwyn Davis, Everest.
2nd row: Brenda Irlam, Theodor Benfey, Stephen Awokoya, Margaret Grunau, June Revai, remaining unknown.
3rd row: Mary Hemming, G. H. Smith, unknown, Samuel Fowden, C. K. Ingold, H. J. Evans, Ronald J. Gillespie, Gareth Williams, Rimmer, Dorothy Usher (Easty).
4th row: Franceska Leake (Garforth), unknown, unknown, unknown, unknown, D. James Millen, unknown, Kathleen Winstanley, Johnston, unknown.

would be permanently labelled as having received a first class degree or a second or a bare pass. Those lectures in somewhat polished form became the Baker lectures at Cornell University published as *Structure and Mechanism in Organic Chemistry*(7).

Ingold's *Magnum Opus*

If we look in detail and from an educator's and historian's point of view at Ingold's *Structure and Mechanism* we meet up with some intriguing discoveries. The preface announces that the book is not intended as a research monograph. Instead Ingold declares, "I have been writing chiefly for the university student, and rightly or wrongly, I have adopted the policy of limitation by selection."

The first chapter, "Valency and Molecular Structure," begins with a historical section, "Development of the Theory of Molecular Structure," pointing to the key figures who helped clarify the numerical aspect of valency: Dumas, Gerhardt, Laurent, Cannizzaro, Frankland, Williamson, Kekulé, van't Hoff and LeBel.

By the end of the century valency had become synonymous with the charge on an element if in ionic form and with the number of bonds. But Alfred "Werner was foremost in maintaining a clear distinction between the charge number of an ion and the coordination number."

By page 3 (2nd page of the text) I already learned something quite fascinating. Ingold talks of the 1897 "discovery of the electron by Thomson and Wiechert." Who was Wiechert—a coworker of J. J. Thomson? No sign of that. It turns out that Emil Wiechert became head of one of the leading schools of geophysics, in Göttingen, and provided some of the basic information about the earth's core, as well as developing a highly sensitive seismograph. He was also much involved in trying to interpret Maxwell's equations of electromagnetism. He measured the e/m ratio of cathode rays at the same time as J. J. Thomson.

However, John H. Heilbron in his account of Thomson in the *Dictionary of Scientific Biography* says Wiechert did not discover the corpuscular nature of elecrons because he was influenced by H. A. Lorentz' ideas about electricity, and identified the cathode-ray particle as a disembodied atom of electricity, a fundamental entity distinct from common matter. Yet Ingold made Wiechert a codiscoverer. Was his judgment more accurate than Heilbron's? Considering our present knowledge of wave-particle dualism, Wiechert's description of the electron may have been truer than Thomson's. We have now found that all of matter is as mysterious as the electron, whereas Thomson claimed that the electron was simply another piece of matter.

In the first quarter of the book Ingold laid the structural groundwork with introductory chapters on physical properties, inter- and intramolecular interaction, and classification of reactions and reagents. He also develops his terminology, the inductive, mesomeric, and electromeric effects and the associated symbolism ± I, ± M, and so on. He then launches into the heart of his subject, the mechanisms of reactions. And he chooses as his first topic not the seemingly simpler aliphatic substitution but rather electrophilic aromatic substitution for very perceptive reasons:

> If organic chemistry had so developed that we could report its position in a completely systematic way, our next proceeding would be to direct attention, for each one of the reaction types surveyed in the preceding chapter, to the principal observations and conclusions concerning its orientation, rate, extent, steric course, and mechanism. However, we shall actually proceed in a less systematic manner for two reasons. One is that the subject of chemical reactions is intrinsically dissymmetric: there can be no orientation problem where only one potential reaction center exists, and no practical question of extent in experimentally irreversible reactions. The second reason is that organic chemistry has in fact developed unevenly.

He then states that one must preserve the "historical perspective ... in order that the present position may be appraised." Now he explains why he has chosen aromatic substitution as the first area to be discussed in detail:

> Electrophilic aromatic substitution almost always involves several potential reaction centers, and therefore presents a problem in orientation; and since orientation can be studied on the basis of a minimum of previous knowledge of reaction mechanism, it constitutes a natural first step in the approach to the problem of mechanism. Moreover the study of orientation historically came first, leading naturally to the comparison of reaction rates, and then to the study of mechanism....

History in Chemistry Elsewhere

Since both Ingold and Conant took it for granted that the only way to understand science was to see its episodes in historical, developmental context, I wondered how general this approach was at the time of Conant's return to Harvard and to Ingold's teaching and Cornell lectures. In Aaron Ihde's bibliographic notes in his *The Development of Modern Chemistry*(8), he comments that "Organic textbooks of the past generally gave considerable attention to historical matters, but this becomes less true of contemporary texts." He then lists a "few of the principal exceptions,"among them textbooks by L. F. and M. Fieser(9), J. B. Conant and A. H. Blatt(10), C. R. Noller(11), J. Read(12), E. Werthheim and H. Jeskey(13), and P. Karrer(14). He also mentions chapters in Henry Gilman's four-volume *Organic Chemistry*(15)and in A. Todd's *Perspectives in Organic Chemistry*(16) and finally says, "Also see C. K. Ingold *Introduction to Structure in Organic Chemistry*(17) and *Structure and Mechanism in Organic Chemistry*(7); and Edwin S. Gould *Mechanism and Structure in Organic Chemistry*(18)." Karrer includes a chronology of important discoveries as well as a list of over 160 compounds detected in coal tar, arranged in order of increasing boiling point, with the name of the discoverer, date and literature reference for each. Wertheim's *Organic Chemistry* includes about 50 photographs of organic chemists (spread throughout the text in order of their birth dates!) with commentary and references to biographical information. His preface seeks to justify the incorporation of history: "Organic chemistry as we know it today is the product of human brains and human hands. It gains in interest when the human element is recognized and at times emphasized in teaching. Nor does this treatment add to the burden of memorization. Every teacher of experience knows that facts 'stick' better when coupled with an anecdote or interesting bit of history." One of his tables is a chronology of organic chemistry from 1500 (Paracelsus' synthesis of ethyl chloride!) to 1931, with references to further listings of American chemical events.

My most interesting discovery was Louis and Mary Fieser's *Advanced Organic Chemistry*(9). In their preface they announce that they have followed a topical presentation and that they tried "to do full justice to history, to modern theory, and to details of experimentation." In place of full references to the literature, which would have defeated their aim of producing a volume of "reasonable size and price," they give guidance to the original literature by name-and-date references, and biographical information about at least one member of a research group. These biographical notations are extraordinarily useful. Here is an example:

> Henry Gilman, b. 1893 Boston; Ph.D. Harvard (Kohler); Iowa State College.

In all, 400 organic chemists are similarly listed with birth place and date, doctoral institution and mentor, and career affiliations. Ingold's listing reads:

> Sir Christopher Ingold, b. 1893 Ilford, England; D.Sc. London (Thorpe); University College, London.

On looking up J. F. Thorpe's listing in the Fieser text we discover that he did his Ph.D. work with K. von Auwers in Heidelberg, who in turn obtained his doctorate with August Wilhelm von Hofmann in Berlin. That is where the trail ends. The Fiesers apologize for not having tracked down the mentors of many of the foreign chemists they list. But for those individuals, other sources are now available such as the *Dictionary of Scientific Biography,* as well as the growing number of chemical genealogies appearing in the historical and chemical-education literature(19).

E. D. Hughes obtained his Ph.D. with Kennedy J. P. Orton, whose kinetics training he then transmitted to Ingold. He also worked with H. B. Watson, student and colleague of Orton. And Orton, like Ingold's mentor J. F. Thorpe, did his doctoral work with von Auwers in Marburg. Auwers was something of a historian himself. A major contributor to stereochemistry, he wrote *Die Entwicklung der Stereochemie*(20).

Among Ingold's former students several have been active in chemical history endeavors. Included among them are John H. S. Green, the honorary secretary of the historical group of the Royal Society of Chemistry, and William H. Brock, who after training with Hughes and Ingold as an undergraduate switched to graduate study in UCL's history of science department. He has become one of Britain's leading historians of chemistry now on the faculty at the University of Leicester. He is book review editor of *Ambix* and has recently published a new and totally original history of chemistry, his Norton/*Fontana History of Chemistry*(6). One chapter in it is largely devoted to Ingold while another is devoted wholly to chemical education, from Edward Frankland and Henry Armstrong to the Nuffield, CBA, and Chem Study curricular reforms.

Derek Davenport, a post-world war II Ingold Ph.D., is another Ingold educator-historian. He has the distinction of being the only person who has directed two four-week Princeton summer institutes for chemistry teachers, one in inorganic chemistry and one in the history of chemistry.

Why the Decline - and now the Resurgence - of Chemical History?

In the half century between 1870 and 1920 there was a powerful movement to make the history of chemistry an integral part of chemistry. During that period Carl Schorlemmer(21), Hélène Metzger(22), J. R. Partington(23), and Edgar Fahs Smith(24) wrote influential histories of chemistry that included much chemical content. These books were largely "internalist" science histories, although Schorlemmer as a Marxist, looked at broader contexts also.

As far as the U. S. was concerned, what motivated Smith and his followers was the realization that many students were the first in their families to be exposed to a university and its broader cultural vistas. And many of those from rural backgrounds were particularly attracted to chemistry. Thus the introductory chemistry course could aid in this broader educational task by showing the historical setting of the science content they needed to learn.

By Conant's time the focus was very different. Conant was concerned that the nonscientist who would take future leadership positions in the nation had no understanding of science. He therefore instituted attractive science courses for nonscientists. But science majors were exempt. Thus the historical-cultural emphasis moved from the science courses to the nonscientists' exposure to science. The new textbook writers for chemistry majors no longer needed to become literate about historical context. They used the "excessive amount of information to be learned" as their rationale for eliminating references to the human side of chemistry. Ingold's success in systematizing organic chemistry may have contributed to the trend because he helped turn organic chemistry from a series of seemingly unrelated reactions to a coherent science, many parts of which can now be taught deductively.

Recently, however, there has been a resurgence of interest in showing to science students the human side of chemistry as seen for instance in the large number of applicants for the 1992 Princeton institute in chemical history and in the formation and growth of the Chemical Heritage Foundation. There have also been a number of new chemical history texts, such as William Brock's, already cited(6), John Hudson's *The History of Chemistry(25)*, and David Knight's *Ideas in Chemistry: A History of the Science(26)*. One reason may be the belated self-consciousness of the chemical community in the face of the public's suspicion and criticism of all things chemical, the concern to demonstrate the significant roles played by the chemical sciences in the intellectual, cultural, and economic development of the last two centuries.

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