Alexander F. Wells and the teaching of solid state chemistry

Alexander F. Wells y la enseñanza de química del estado sólido

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Abstract

A.F. WELLS, who pioneered the classification and representation of structures exhibited by inorganic compounds, received his PhD in X-ray crystallography from Cambridge in 1937. In the few years following his graduation, he started to contemplate bringing some order to the field of inorganic structures. He wrote the first edition of Structural Inorganic Chemistry during World War II, the book being published in 1945. During his lifetime, the book went through five editions, and it is still a classic and useful reference book. The environment in which this creative enterprise was carried out is explored in his family history. WELLS was early on convinced that structures can only be appreciated and learned by building models and contemplating them. This conviction resulted in two additional books. The challenge as to how structures should be taught is still not completely fulfilled.

Key words: *molecular properties/structure, solid state chemistry, X-ray crystallography.*

Resumen

A.F. WELLS fue pionero en la clasificación y representación de las estructuras de los compuestos inorgánicos. Recibió su PhD en cristalografía de rayos X de Cambridge en 1937. Pocos años después de su graduación, comenzó a hacer un cierto orden en el campo de estructuras inorgánicas. Escribió la primera edición de La Química Inorgánica Estructural, en la Segunda Guerra Mundial, libro publicado en 1945. Durante su vida, el libro pasó a través de cinco ediciones, y sigue siendo un libro de consulta clásico y útil. El ambiente en el cual esta obra creativa fue realizada, se explora en sus antecedentes familiares. A. WELLS era uno de los primeros convencidos que las estructuras pueden ser apreciadas y aprendidas solamente construyendo modelos e investigándolos. Esta convicción dio lugar a dos libros adicionales. El desafío en cuanto a cómo las estructuras deben ser enseñadas, es todavía el problema en la enseñanza.

Palabras clave: *características moleculares/estructura, química de estado sólido, cristalografía, rayos X*

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INTRODUCTION

Students of chemistry are expected to know something of each of the traditional areas of chemistry, that is, organic chemistry, inorganic chemistry, analytical chemistry, and physical chemistry. A descriptive inorganic chemistry paper today would not be complete without the elucidation of the structure of the material being studied. Students reading the literature of inorganic chemistry are, therefore, expected to glean information of the structural representations presented. Structures are illustrated using variations of the ball and stick, polyhedral, and close packed representations. In reading the descriptive inorganic papers, a student should recognize the pioneering role played by the text "*Structural Inorganic Chemistry*" by A.F. WELLS. In addition, an appreciation of a discipline requires the knowledge of a bit of history.

In order to understand inorganic compounds, one has to know what atoms are connected to what other atoms, and ultimately to know something about bond angles and bond lengths. Until the early part of the 1900s, inorganic compounds were characterized by their reactions in solutions, by the analysis of their elemental composition, and by their crystal habit. For example, the formula of zinc sulfide could be deduced as ZnS from analytical procedures that give rise to one atom of zinc and one atom of sulfur making up the zinc sulfide. The connectivity, or topology, could be further studied by characterizing the species that formed in solution. For example, sulfuric acid and barium chloride would form a precipitate of barium sulfate. More complex topologies were elucidated by the inspired observation of the color of related compounds and the number of isomers formed. For example, Werner deduced the chemistry of coordination compounds by the number of isomers, optical and geometric, that were formed. Structures that involve not only topological information, but bond lengths and bond angles could not be rigorously confirmed until the advent of X-ray diffraction. It was not until after Bragg and Bragg demonstrated in 1912 how information from the scattering of X-rays by a three dimensional diffraction grating could be used to determine structures that Werner's postulates could be unequivocally proven some 10 years after the pioneering work by the Braggs.

Figure 1. A.F. WELLS (with pipe) at a crystallographic conference in Montreal, 1957.

In the early days of crystallography, computers were not available. Calculations of structures from X-ray data were done by tedious hand or mechanical calculation of Fourier series equations. As recently as 50 years ago, graduate students would complete a PhD thesis based on the determination of a single structure. With the advent of better and better computers and with the advent of improved X-ray sources, the structural determinations became more rapid. Inorganic chemistry is now in a situation that a new compound is not published until the X-ray characterization is done. The time needed for these determinations is now measured in weeks rather than in years.

There were only 25 to 30 years of data accumulation from X-ray crystallography of inorganic compounds when A.F. WELLS started to ruminate on some ordering of this information. Advances in science are generally the result of discussion, collaboration, and competition between individuals and laboratories. Occasionally, a single individual makes a contribution more or less as an individual. Einstein's development of the Theory of Relativity is a case in point. WELLS was not only a person who worked well by himself, but it should be noted that the world was engulfed in war when he started to cogitate about structures. The first of the five editions of *Structural Inorganic Chemistry* was published in 1945 by Oxford/Clarendon Press. It was largely written during the years when the Second World War was raging. Because of the War effort in Britain, the scholarly life in the Universities was disrupted as scholars became involved directly in the armed forces or were assigned to technology development needed for the war effort. The collegial atmosphere of scholarly interactions in academia was disrupted. In order to understand how the ideas expressed in *Structural Inorganic Chemistry* were developed at this time in history, a background on Wells' personal life is helpful. This historic background was especially useful as structural concepts were incorporated into the teaching of inorganic chemistry during Wells' tenure as a professor at the University of Connecticut.

Figure 2. A.F. WELLS at home in Connecticut. Pictured is the portable Corona typewriter used to type all of his books.

ALEXANDER F. WELLS, known to his friends as Jumbo, did his graduate research on the structures of inorganic compounds. It must have initiated his thinking about how the structural information being published could be systematized. WELLS, who received the PhD in 1937, must have started to collect data as an expression of his passion to understand structures of inorganic compounds. This passion that was nurtured while doing research for the war effort that then resulted in the writing of the first edition of "*Structural Inorganic Chemistry*" published in 1945. In his book, he noted that only a few inorganic compounds are molecular in nature, but that most inorganic solids have one, two, or three-dimensional infinitely repeating patterns. WELLS classified the known structures into groups with related patterns. He pioneered the classification of structural types by use of close-packed models, polyhedral models, and ball and stick models. In the WELLS concept of infinite structures, the stoichiometry is given by the repeat pattern. Analysis gives the stoichiometric ratio of atoms in that the edge effects are negligible compared to the very large number of properly repeating units. It was as an individual effort that the development of these ideas was taking place while World War II was raging. WELLS was assigned to war work developing phosphors to be used in CRTs and in helping service people move about in the dark. This meant that his writing was pursued in the evenings after a day of defense work.

To understand his life, the children in the WELLS family were interviewed. These were, with year of birth in parentheses, EALEY (1928), ELIZABETH (1930), ALEXANDER (1942), and JANET (1944). It is hoped that these interviews will give an insight into the environment that gave birth to "Structural Inorganic Chemistry." This book is a unique text as well as a reference book. It introduced inorganic chemistry to a way of looking at three- dimensional finite and infinite structures of inorganic solids.

JT: Elizabeth, you and your older sister Ealey were living with your widowed mother when Jumbo appeared on the scene and married your mother. What are your memories of this time?

Elizabeth: My mother was widowed in 1935 when my father went into the hospital for a minor operation and developed complications and was lost. Ealey and I were 7 and 5 at the time. After father passed away, we moved to Cambridge. Mother was invited to go on a boating outing with a gentleman friend who brought his friend Jumbo along. It was not long before Jumbo was the man in the picture. Jumbo and mother were married in 1939 soon after Jumbo was granted the PhD by Cambridge University. Ealey and I were 11 and 9 when mother and Jumbo were married.

JT: Was Jumbo already working on his *Structural Inorganic Chemistry* book at the time your mother and he got married?

Ealey: After mother and Jumbo got married, I recall Jumbo working with piles of paper on the dining room table after tea. He must have been starting to organize his thoughts for his book. Because I was being assigned homework at school, I was also kept busy with studies in the evening. As I recall, the actual writing started after we moved to Birmingham.

JT: Ealey, your observations are interesting in that if we assume that Jumbo started the writing in 1940 after the move to Birmingham, he would have been about 28 years old. The writing of the first edition must have been finished around 1944 since the publication date of the First Edition is 1945. This landmark creative effort was, therefore, done in Jumbo's late 20s and early 30s.

To get back to Jumbo's life, can either of you shed light on his early years?

Elizabeth: Jumbo was born in London on September 2, 1912 to Alexander Edward and Emma Isabel (Wilkes) WELLS. There were three boys in the family. The eldest died of meningitis at the young age of 29. Jumbo was the middle son. The youngest son, John, emigrated to Canada after the end of the war. Jumbo's father was apprenticed as a young boy to a textile mill. He spent the rest of his working days working in the textile mill. Even though he lacked formal education, Jumbo's father had an interest in chemistry. He had a shed out in the garden where he did chemical experiments, woodwork, and fixed his motorcycles. I would guess that this is where Jumbo picked up his interest in the sciences.

JT: Alexander, as your father's namesake and as an aeronautical engineer, did you learn anything of Jumbo's school years and his admission into Oxford?

Alec: Because Dad's parents were not well off, the only way he could attend college was to get a scholarship. Early on, one of his school teachers said that he would never be able to get a scholarship. Dad proved her wrong by obtaining a scholarship to Queens College, Oxford. Dad did not talk much about his school days, but this must have been the time when he developed his skills in making fireworks, probably with his father. I don't know any of the details of what happened during his studies in school.

JT: Janet, Jumbo lived with you for the last seven years of his life. After retiring as Professor of Chemistry from the University of Connecticut, and after your mother Ada passed away, he sold his home in Mansfield, Connecticut and returned to England at the end of 1986 because all four of you children lived in England. Because he lived his last years with you, do you have any records of his university studies?

Janet: To the best of my knowledge, Dad obtained his BA from Oxford around 1933. Following this, he enrolled in the graduate school at Cambridge. I don't know the background of his move from Oxford to Cambridge, but I presume that it was the general custom for students to do their graduate work at another University from that where the undergraduate degree was earned. I have Dad's Ph.D. thesis. I believe that his graduate research was guided by Prof. J. D. Bernal because in the preface to his thesis he states: "The author would like to thank Mr. J. D. BERNAL for his stimulating and helpful advice during the course of the work, and for making optical examinations of some of the compounds." The subject of the thesis was crystallography. Of the three chapters, the first was titled "Tertiary Arsine and Phosphine Derivatives of Cuprous, Argentous and Aurous Halides." The structure of triethylarsine cuprous iodide was determined together with the related compounds of copper, silver, and gold. The second chapter was titled "Crystal Structures of the Mercury Mercaptides." This chapter describes the structure of diethyl mercaptide as well as the higher members of the series. The third chapter is titled "The Configuration of the Tetranitro-diammino-cobalt Ion and the Mechanism of Replacement in Co-ordination Complexes. His thesis was submitted in the Easter Term, 1937 and was titled "The Crystal Structures of Certain Complex Metallic Compounds."

JT: Janet, your supposition with regards to Bernal is correct. The archives at Cambridge University indicate that your father's supervisor was indeed J. D. Bernal. His examiners, both internal to Cambridge University, were J. D. Bernal and F. G. Mann.

JT: Ealey, you mentioned what you thought was the earliest stage in the writing of *Structural Inorganic Chemistry*. Do you remember what came next?

Ealey: As my sister Elizabeth has said, mother and Jumbo were married in 1939. Shortly thereafter, we moved to Birmingham where Jumbo was involved in research to support the war effort. Both Elizabeth and I can recall the bits of phosphor-coated pieces that Jumbo brought home for us to see. The object was to develop a phosphor that might emit light for a long time after being exposed to light. This was so that the sailors on darkened ships could find their way around in total darkness.

It was in Birmingham that Dad began to write his book. He spent every evening typing on the manuscript. We were all to keep quiet. The radio could not be turned on. Mother usually knitted or read. I did not feel constrained because I had my own school studies to do. In fact, it was in Birmingham that I got to know Jumbo as a father. We walked together a fair distance each morning to the tram to take us to our destination. The school I attended was very close to the research laboratories where Dad worked. The production of the book was quite separate from his war work in the laboratory.

JT: Your mother was, in retrospect, a very remarkable woman. Most wives would demand time from their husbands. She apparently was fully supportive of Jumbo's project and was willing to allow him to spend enormous amounts of time at his writing.

Ealey: Yes, mother was a very understanding person. Even though Jumbo was devoted to his work, there was a great deal of devotion to each other. The evenings were not all work. For a half an hour before retiring, Mother and Dad worked on jig saw puzzles. As everyone was getting ready to retire, Dad would play the piano.

JT: To get back to the progression of the book, I note that the family moved to Manchester in 1944 where Jumbo went to work for Imperial Chemical Industries. Was the writing complete at this time?

Janet: The writing of the first edition must have been completed by this time. Of course, I don't remember much since I was born just before the publication of the First Edition. I do remember as a child going to bed each night hearing the sound of the typing through the floor of my bedroom. Apparently, Dad started work on the following edition as soon as one updated edition was finished. (First Edition, 1945; Second Edition, 1950; Third Edition 1962; Fourth Edition, 1975, and Fifth Edition, 1984) Dad did all of his writing on a fold-up portable Corona typewriter that is pictured with Dad when he was in Connecticut. I think that this same typewriter was used to type his thesis as well as all of the pages of the five editions. I still have his old typewriter in my possession.

JT: Alec, what are your memories of your father's work? You were about 8 years old at the time of the publication of the Second Edition. I remember being shown the typewriter when he was living in Connecticut. It amazed me that so many words could have been produced on what almost seemed like a toy.

Alec: The typing was only one part of the production of the book. Father spent a great deal of time on the illustrations of the structures of the various compounds being described. He used India ink. I can remember in the early days that he would buy rectangular sticks of material that had to be ground with water to make the ink. He was meticulous in carefully making some lines a bit broader than others. There were no computer graphics back in those days, and all the drawings had to be done by hand. He did all the drawings himself instead of turning them over to an illustrator.

As I grew older, father interested me in helping to make models. At various times we made three-dimensional models of repeating structures. We used an assortment of materials, including punched paper strips, cut-down bicycle spokes, flexible plastic commercial items, and parts of his model kits. Mother did not like blobs of solder on the table, and we did not have any jigging tools to start with. Sometimes we used techniques developed by his laboratory technicians. I made some jigs for constructing some of the structures. He and I would play with the bits and discuss new ideas. There was not much to connect any of this with my school-boy chemistry studies. Father was off on a different plane.

We were both fascinated by some of the repeating surfaces we could produce with the later models, dividing space into two equal intermeshed volumes, for example. This seemed to me to be far removed from his stick and ball molecular geometries, but he had an unfettered view of spatial relationships. I remember father said we were all constrained by seeing life (and space) from the inside or outside of cuboids. Nowadays we might think how much easier it would be with computers, but it is hard to imagine starting to think about that sort of geometry without the real models to examine.

JT: Many advances in science are made by a group of people. Sometimes these people work together. At other times, there are several separate groups that interact in one way or the other. The development of quantum mechanics involved a number of people such as Bohr, Schroedinger, Sommerfeld, Heisenberg, and others. The development of organic chemistry mechanisms involved Robinson, Ingold, Hughes, and many others. In a few instances, a single individual makes a seminal contribution. It seems to me that Jumbo's organization of descriptive inorganic chemistry based on structural types was done more or less in isolation. Did your father have regular interaction with other crystallographers?

Alec: I do not recall many home visitors connected with his professional interests - Garlick and Beynon lived locally and sometimes dropped in. I remember we had a lot of international mail. What I remember are the Friday evening musical gatherings. A number of different amateur instrumentalists would gather at the house to produce music. We were allowed to listen if we kept still. I can recall an excellent French Horn player and a violinist who played in the Halle Orchestra, a well-known orchestra based in Manchester. Father, of course, played the piano. Those who gathered on Friday nights were brought together by a common love of music and were not usually his co-workers at ICI. One exception, however, was HENRY THOMPSON, an ICI director, who started playing the flute and progressed at a remarkable rate. The musical sessions would last from 7:00 or 8:00 pm to well past 11:00. It was fortunate that the bus service past our house in South Manchester continued all night.

JT: That Jumbo faithfully attended the crystallographic conferences is consistent with my observation on how he carefully scanned the literature for new inorganic structures. He had a unique way of keeping a record of each new structure described in the literatures. Also, Janet, your observation that your father was rather alone in developing the contents of *Structural Inorganic Chemistry* is consistent with the observation that a large number of papers that he published (list attached) were without co-authors.

JT: Do you know, Janet, the circumstances under which your father left ICI and went to the United States to join the chemistry department at the University of Connecticut?

Janet: Dad was in his 50s and was determined to avoid the administrative or managerial posts that he was being offered at ICI. There was a lot of pressure to accept these positions. He was concerned that he might be offered a "golden handshake" after not accepting these very generous offers from ICI. Because he wanted to continue to work, he was receptive to the idea of taking an academic job. He, therefore, took the NSF Visiting Scientist position offered to him by prof. ROLAND WARD for the 1965-66 academic year at the University of Connecticut. He enjoyed his year in Connecticut, and, as evidence of his interest in teaching, he wrote a book on the teaching of structures using models after his return to England (*Models in Structural Inorganic Chemistry.)*

JT: It was a wonderful thing for the Inorganic Chemistry Division of the University of Connecticut to have been able to interest your father into returning as Professor of Chemistry starting with the 1968 academic year. On your father's return, he was able to use his *Models in Structural Inorganic Chemistry* teaching text on a tutorial basis with a few of the graduate students. I happened to be assigned to teach the senior inorganic chemistry course at the time. Your father and I worked on different schemes for teaching structures to the undergraduates. We recognized that all of the laboratory exercises of the one-semester course could not be the building of models. At first we organized a five laboratory-period sequence of model building. Because this took too much time from the practical laboratory exercises, we then condensed the model building to two laboratory-periods. With the course reorganizations that took place over the period of years resulting in an increased number of laboratory periods, we now use three laboratory- periods dedicated to model building.

JT: We noted earlier, Janet, that your dad came back to England and lived with you after your mother passed away. Did he continue his contemplation of structural types during this period?

Janet: He was very active in studying the properties of three-dimensional nets until he suffered a stroke. The stroke occurred less than a year after he returned to England. It was in September 1987. He recovered sufficiently to be able to take long walks, but his power of speech never fully returned and his right hand was not very useful. He could still play the piano with his left had, but I had to do the right hand. This wasn't very satisfactory, and he soon lost interest in trying to play the piano.

JT: I remember one thing that took place when I visited Jumbo at your house in England. This was after he had suffered his stroke. At the University of Connecticut, he had a model showing how the transition from body-centered cubic to face-centered cubic might take place. When one looks at the unit cells, this is hard to visualize. However, a common exa-

mple in inorganic chemistry is the transformation that iron exhibits. Below 906°C, iron crystallizes in the body-centered cubic structure. At 906 to 1401°C, it exhibits the face-centered cubic structure. Above 1401°C, the body-centered structure again becomes the stable structure. To explain these transformations, Jumbo had a model. After he returned to England, I could not find this model. I asked whether he had brought it back to England with him. He shook his head no, and then proceeded to go to the bookshelf where he took down a book, and without looking at the index, flipped through the pages until he found where this model was described. I was amazed that his mind was as sharp as it ever was.

There are things we remember about Jumbo. He was an especially gifted writer. Whereas many of us do several or more revisions on our writing, Jumbo would put it down properly the first time. He had a lifelong fascination with structural chemistry. He contemplated the possible geometrical arrangements of atoms in crystals. He worried about topology. He recognized that, at times, geometry was as important as molecular orbitals in the types of structures exhibited by solids (e.g. cristobalite and β-quartz). He not only worried about the structures of the known compounds, he worried about the possibilities of structures that seemed to be geometrically possible. He was happy when someone would report a structure that he recognized as fitting into his list of geometrically possible compounds. He spent a great deal of time looking at three and four connected nets to determine what structures may yet turn up. He didn't seem to need the interaction with others; he only seemed to need the way nature put crystals together to stimulate his creative thinking. He was capable of long, hard, tedious work. Yet he enjoyed and found time for music and gardening. His contribution to the field of inorganic chemistry was enormous. In looking over the pages of the Journal "Inorganic Chemistry," it seems that most of the papers owe something to WELLS for the ways in which the structure of a new compound is described. WELLS recognized that structural inorganic chemistry could not be taught by way of lectures. He was a proponent of presenting the material in a laboratory setting. We, at the University of Connecticut, have found the lab approach to be successful. Others wanting to try this approach can use the *Models in Structural Inorganic Chemistry* book as a resource for developing undergraduate laboratory exercises. As we appreciate the contributions of WELLS to inorganic chemistry, we cannot overlook the contribution of Ada WELLS in having supported her husband for a lifetime of dedication to chemistry. She also showed appreciation for his piano playing and fussed over the vegetables he grew in the garden.

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