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BOOK REVIEW

Eric Scerri: *A Tale of 7 Elements*

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This is a book which will appeal to historians, philosophers, chemists, and educators. Of the ninety-two elements up to uranium only seven were missing from the periodic table around 1913. The story surrounding the identification of these seven elements forms the core material of the book. The seven elements in the order of their identification dates are: element 91- Protactinium (1917 by Meitner); element 72- Hafnium (1923 by Hevesy); element 75- Rhenium (1925 by Noddacks); element 43- Technetium (1937 by Segrè); element 87- Francium (1939 by Perey); element 85- Astatine (1940 by Segrè); and element 61- Promethium (1945 by Marinsky). What is interesting is that each block of the periodic table is represented by at least one of these elements. One of the elements is from the *s* block, one from the *p* block, three from the *d* block, and two from the *f* block.

While Scerri is known for his philosophical claim that chemistry cannot be reduced to physics, that is, electron configurations derived from quantum mechanics cannot provide a complete explanation for the chemistry of the elements, he does acknowledge that such configurations can provide insight into certain chemical behaviours. A good example of this is given on page 190 where he distinguishes the behaviour of the main group elements (*s* and *p* block) from the transition elements and the rare earth elements.

> But what bearing do electronic configurations have on this issue? The answer lies in the fact that as one crosses the transition metal block of elements, the new electron that differentiates each atom from the previous one, with a few exceptions, is added to the penultimate rather than the ultimate or outermost shell…Meanwhile, in the case of traversing the rare earth block, the electron that differentiates the atom of each element as one moves across the table is occupying a shell that is even further from the outer-shell, namely two shells (in) from the outer-shell.
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> The chemical result of these subtle electronic effects is rather profound. On moving across a short period that involves only the so-called main-group elements, such as beryllium, boron, carbon, and nitrogen, one sees a large difference in chemical as well as physical properties. Here the differentiating electron is entering an outermost shell and, given that the properties of atoms are governed by the number of electrons in the outer shell, we observe a large variation of properties.

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> As we move across the first transition series…the differentiating electron occurs in the penultimate shell, with the result that the variation in properties is less pronounced than across a series of main-group elements. Finally, when it comes to crossing the rare earth series, the variation in properties is even less pronounced, to the point that the elements are almost identical as a result of the entry of successive differentiating electrons at a distance two shells in from the outer shell…For the rare earths, not just one but two outermost shells are the same.

Five of the seven elements belong to the *d* block or *f* block and this signals some of the difficulties chemists faced in differentiating one element from another. For example, protactinium has similar properties to tantalum vertically above it in the periodic table and similar properties to thorium and uranium horizontally adjacent to it in the periodic table. The vertical relationship suggests protactinium is a transition element and the horizontal relationship suggests it is an actinide. This proved to be a rather difficult problem to resolve but the consensus now is that it should be regarded as an actinide.

1 Small Targets

One of the reasons these seven elements were the last of the ninety-two to be discovered was their relatively low abundance in the earth's crust. There is about 0.01 ppm of rhenium in the earth's crust; about 2×10^{-10} g of ^{99}Tc per kg of pitchblende ore; only about 30 g of francium in the whole of earth's crust; and about 4×10^{-15} g of ^{147}Pm per kg of pitchblende ore, just to take some examples. Low abundance can be the result of the isotopes of the element being radioactive with short half-lives. There are nineteen known isotopes of protactinium, all having half-lives of less than 1 month. The longest lived isotope of francium has a half-life of about 21 min. The potential of short half-life elements for use in medicine is a topic of current research. Scerri discusses the use of ^{99}Tc in medical imaging due to its suitable half-life of about 6 h and its emission of gamma rays. Potential and current use of each of the seven elements is a feature of the book.

2 Discovery and Dispute

Low abundance of elements leads to an interesting discussion of what one might mean by the so-called 'discovery' of an element. Scerri discusses this issue quite insightfully in his introduction to the book and the historical details associated with the 'discovery' of each element give witness to this rather difficult issue. Is the 'detection' of an element through its X-ray spectrum or its radioactive properties sufficient to warrant the word 'discovery'? Should the classification of a 'discovery' be limited to the preparation of a pure sample of the element? In 1917 Lisa Meitner used the radioactive properties of protactinium to detect it in a sample of pitchblende. The new element was expected to emit alpha particles and lead to the production of actinium and this is exactly what Meitner found. However, it wasn't until 1934 that Aristid von Grosse extracted a sample of the element and not until about 1960 that the Atomic Energy Authority in the UK extracted 125 g of protactinium from 60 tons of waste uranium minerals. X-ray spectroscopic data was used to detect the presence of rhenium in 1925 but it was not until 1929 that a 1 g sample of rhenium was obtained after an arduously long extraction from 660 kg of molybdenite. While astatine was detected from its radioactive properties, it "has the dubious distinction of being one of very few solid elements that has never been obtained in any amount large enough to be visible to the naked eye" (p. 173).

Difficulties associated with extracting low abundance elements from their ores combined with problems associated with interpreting X-ray data has led to major priority disputes related to the discovery of the elements. Scerri portrays these disputes for each element as a detective story which makes for interesting reading. He classifies the dispute over element 72-Hafnium as “one of the most bitter and acrimonious priority disputes in twentieth century science” (p. 91). The controversy raged between the French scientists Dauvillier and Urbain and a Danish school at Bohr’s Institute in Copenhagen consisting of the Dutch scientist, Coster, and the Hungarian scientist, Hevesy. On the basis of X-ray spectroscopic evidence, the French school maintained that hafnium had to be a rare earth element, but the Danish school, also on the basis of X-ray spectroscopic evidence, claimed it had to be a third row transition element. The proposed two faint X-ray lines in Urbain’s sample could not be seen by others when looking at the spectrum. The Copenhagen sample, based on zirconium ores, produced six X-ray lines which were in agreement with those expected from Moseley’s law. The consensus is that Urbain’s data was more consistent with element 71 than with element 72. An additional problem for chemists was that zirconium, a second row transition element, and hafnium, now regarded as a third row transition element, have such similar chemical properties that hafnium could not be separated from zirconium by chemical means. Separation could only be achieved by the differences in physical properties.

There were many false claims as to the identity of element 61- Promethium. All claimants appealed to X-ray data and Moseley’s law but the data and the law were indecisive. Part of the problem was that promethium was highly radioactive and unstable and of very low abundance, and its consequent very faint X-ray spectrum appeared in the presence of elements 60, neodymium, and 62, samarium, typical of the behaviour of rare earth elements. Separation of element 61 had to await the development of a new technique called ion-exchange chromatography. It turns out that Moseley could only predict the existence of elements 43, 61, and 75 with any degree of confidence and Scerri reminds us that “Moseley’s law is not quite as powerful as often portrayed” (p. 176).

3 Element–Natural or Synthetic?

The natural occurrence of some elements was only discovered after they were first artificially synthesised. Element 43- Technetium, was the first element to be artificially synthesised and the first instance where an element was discovered in an ore body only after its artificial synthesis. The synthesis involved irradiating a plate of molybdenum with deuterons and neutrons. In relation to this, Scerri provides an important historical observation often lost in the new generation of chemists: “The simple fact is that for many years the artificially synthesised elements were not considered as true elements by all chemists” (p. 133). It was only in 1968, 23 years after its discovery in 1945, that traces of technetium were found in a sample of pitchblende ore and one is left to wonder what would have become of the status of technetium if this had not been the case. The importance of the nuclear industry since 1945 may have saved the day for technetium.

4 Chemistry Reduced to Physics?

Mention has already been made of the author’s use of electron configurations for giving insight into the chemical behaviour of the main-group, transition, and rare earth elements.

However, it is also obvious throughout the book that the author believes that chemistry cannot be entirely reduced to physics. This becomes apparent in his comparison of the predictions made by the chemist Brauner and the physicist Moseley. While Moseley could predict only elements 43, 61, and 75 with any degree of certainty, Brauner was able to predict elements 43, 61, 72, 75, 85, 87, and 89. Other examples are as follows:

> But the fact that the third shell can contain 18 electrons does not strictly explain why it is that some of the periods in the periodic system contain 18 places. It would only be a rigorous explanation of this fact if electron shells were filled in a strictly sequential manner (p. 55).

> Whereas the rules for the combination of four quantum numbers provides a rigorous explanation for the point at which shells close, it does not provide an equally rigorous explanation for the point at which periods close (p. 56).

> The conclusion, seldom acknowledged in textbook accounts, is that quantum physics only partly explains the periodic table. Nobody has yet deduced the Madelung rule used to predict the overall configuration from the principles of quantum mechanics (p. 57).

> Chemical periodicity is a remarkably robust phenomena. Not even the powerful relativistic effects due to fast moving electrons seem to be capable of toppling a simple scientific discovery that was made about 150 years ago…..one must be open to surprises of course….This seems to be a further testament to the underlying fundamental nature of the periodic law, which continues to stand firm against the threats from quantum mechanics and relativity combined together (pp. 206–208).

5 A Complete or Incomplete Table?

Some of the material from the author's earlier text, *The Periodic Table*: *Its Story and Its Significance* (Scerri 2007), is included in the first two chapters, particularly material related to the earlier discoverers of the periodic law. This is used by the author to provide a background for what follows on the discovery of the remaining seven elements and how the periodic law is featured in this. Chapter 10 of *A Tale of 7 Elements* gives a brief picture of the synthesis of new elements and questions whether there could be an upper limit in atomic number achievable in synthesis. The definite impression is created that the periodic table is not a closed story but one that is still unfolding. This captures the interest of the reader. Even as late as 2005, Yoshihara was making a case for the discovery of the element rhenium by the Japanese scientist Ogawa at an earlier date than 1925. Scerri gives a solid account of this scenario and provides his assessment of the claim. The detail confirms again how difficult the discovery of these seven remaining elements proved to be.

Extensive notes for each chapter are provided at the end of the book as is a fairly extensive bibliography. The *Tale* forms a useful companion text to the author's *Periodic Table* but is also complete in itself in that it focusses on those elements which proved very difficult to detect or isolate. It is compulsory reading for those who wish to inject some life into the story of the elements and the periodic table.

Reference

Scerri, E. R. (2007). *The periodic table: Its story and significance*. Oxford: Oxford University Press.