Book Review

What is a Chemical Element? A Collection of Essays by Chemists, Philosophers, Historians, and Educators. Edited by Eric Scerri and Elena Ghibaudi. New York, NY: Oxford University Press, 2020, 312 pp. ISBN: 9780190933784, £65.00

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Compared to its sister disciplines—philosophy of physics and philosophy of biology—philosophy of chemistry remains a relatively young field of philosophical endeavour. Having originated in the late 1980s, its initial focus was mostly on the alleged reduction of chemistry to physics versus chemistry's autonomy as a special science. Since then, philosophy of chemistry has significantly broadened its domains of interest.

The focus of the present work, edited by Scerri and Ghibaudi, is the nature and evolution of the concept of a chemical element—a concept so central and foundational to chemistry that is has often been used to ontologically demarcate this science from physics or biology. *What Is A Chemical Element?* brings together a collection of 14 essays, expertly written by a diverse group of scholars—predominantly philosophers and historians, but also chemists and educators. The editors are to be congratulated for assembling such a strong cast of contributors.

The first essay, written by Scerri, serves as an introduction to the subject matter. Scerri, however, raises more questions than answers. As a matter of fact, Scerri concludes his chapter with a set of seven open questions concerning the two senses of element "in the hope of fostering future discussions among ourselves" (p. 22). But while Scerri is quick to point out that many of the questions will be addressed in the present volume, no essay ever refers back to Scerri's list. All in all, the book contains very few internal cross-references, as the contributors do not actively engage with one another. As a result, most chapters read like stand-alone essays, and the volume as a whole feels somewhat loosely bound together.

Considering the above points, the addition of a concluding chapter by the editors would have been worthwhile. By pulling together the different strands of this book and highlighting the main themes and points of contention, the editors could have briefly addressed where we currently stand: Which questions from the introductory chapter have been satisfactorily answered? Which remain open? And which new questions have to be added to the list in view of the current essays?

Despite these critical remarks, there is much to be applauded in this book. First, every essay, without exception, is expertly written and thoroughly researched by seasoned scholars in the field. Second, as indicated by the subtitle, the book has a wide range, covering not only the history and philosophy of the concept of element, but also its educational aspects.

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The Historical Dimension

The more historical essays focus on the development and evolution of the element concept from the Greek philosophers (Empedocles, Plato, Aristotle) via the early-modern chymists (Sennert, Gassendi, Boyle) to Lavoisier, Dalton and Mendeleev. Despite their historical importance, neither Aristotle's four-element theory (water, earth, fire, air) nor Paracelsus' *tria prima* (sulphur, mercury, salt) receive much attention in the book; they are, at most, mentioned in passing in order to draw the contrast with what came after. And while Banchetti-Robino briefly looks at the theories of the early-modern chymists, most authors begin their discussion of the element concept with Lavoisier's definition of the element as the endpoint (or provisional limit) of chemical analysis.

Lavoisier's operational definition was of course tremendously successful. To wit, the number of known elements grew from 33 elements in Lavoisier's time to no less than 63 elements in Mendeleev's time. And yet, in a particularly illuminating essay, Bensaude-Vincent argues that, contrary to common opinion, Lavoisier's notion of an element was actually an "impoverished notion" (p. 35) which was "far too weak to offer the explanatory power of the traditional polysemic notion of chemical elements [as property-bearing principles with chemical affinities] that prevailed in mid-eighteenth-century chemistry" (p. 36). This resonates with Schummer's verdict that the operational turn in chemistry led to a radical disruption which consisted in (temporarily) giving up explanation. "Chemists focused on discoveries, both of new elements and their combinations, and postponed explanation", writes Schummer (p. 172).

Banchetti-Robino picks up the narrative and recounts how Dalton reconciled Lavoisier's notion of elementarity with the ancient notion of atomicity, by postulating for each element a unique type of atom with characteristic atomic weight. Surprisingly, nowhere does Banchetti-Robino allude to the ontological malaise that ensued from the marriage of chemical atomism with Lavoisier's analytical definition of chemical elements.

In short, since Dalton defined the chemical atom as the smallest quantity of a substance that still retains the properties of the whole, Dalton was forced to assume that the Lavoisian elements were actually present in their compounds. Yet most of the defining properties of the Lavoisian elements were mysteriously lost upon formation of new compounds. It was far from clear therefore in what sense the elements survived chemical change. As most authors in this volume acknowledge, it was the father of the periodic law, Dmitrii Ivanovich Mendeleev, who first proposed a solution to this pressing problem of element conservation. As Mendeleev (1891, 23) explained:

> "It is useful in this sense to make a clear distinction between the conception of an element as a separate homogeneous substance, and as a material but invisible part of a compound. Mercury oxide does not contain two simple bodies, a gas and a metal, but two elements, mercury and oxygen, which, when free, are a gas and a metal. Neither mercury as a metal nor oxygen as a gas is contained in mercury oxide."

Brooks further elucidates the origins of Mendeleev's abstract element definition, prior to his writing of the *Principles of Chemistry* and subsequent discovery of the periodic law in 1869. To conclude, while the distinction between simple and compound was central to Lavoisier's work, Mendeleev instead focussed on the distinction between simple/compound bodies and elements. "Simple bodies were treated as *explananda* and the notion of element as *explanans*", writes Bensaude-Vincent (p. 43). "This conceptual shift marks the end of the compositional paradigm [of Lavoisier] and the advent of a new paradigm, a true *elemental chemistry* distinct from Lavoisier's *elementary chemistry*."

The Philosophical Dimension

With Mendeleev's distinction, we have arrived at a central theme that recurs throughout the book, *viz.* the dual notion of the element. It figures not only in the historical essays, but is at the heart of most conceptual and philosophical essays. Several essays, for example, deal with the ideas of Friedrich Paneth, an Austrian radiochemist, who authored many influential papers on the concept of element in the years between 1916 and 1962. In one of his papers, Paneth (2003, 132) asked the reader to consider the following sentences:

1. Copper oxide consists of copper and oxygen.
2. Copper is a metal; oxygen is a gas.
3. Therefore, copper oxide consists of a metal and a gas.

Despite the truth of premises 1 and 2, the conclusion 3 is obviously false. Echoing Mendeleev, Paneth explained that the fallacy is based on the use of 'copper' and 'oxygen' in two different senses. The first sense is that of the element as *basic substance* (or *Grundstoff* in Paneth's terminology), and refers to that which survives chemical change. The second sense is that of the element as *simple substance* (or *einfacher Stoff*) and refers to the endpoint of chemical analysis. The same duality (or ambiguity, if you will) is still present in the current official definition of an element, as established by the *International Union for Pure and Applied Chemistry* (IUPAC).

As the editors observe, "the ambiguity of the concept of chemical element is far from being resolved", and remains "a matter of discussion among philosophers" (pp. 2-3). Indeed, multiple, oftentimes competing, definitions of the element concept are given throughout the book. While Mahootian argues that both senses of the element are needed—they are not contradictory, but complementary—most contributors take issue with the dual definition. Both Earley (p. 109) and Ghibaudi et al. (p. 258) reject the duality for being "inherently contradictory" and "inconsistent". In an attempt to get rid of this lexical ambiguity and "strange allowance for polysemy" (p. 144), Earley makes the terminological suggestion to only use the term 'element' for the element as basic substance (*Grundstoff*). Hijmans also proposes a single element concept, but one with two 'aspects'—a theoretical and an empirical one (the same distinction, incidentally, was already drawn by Paneth in the closing remarks of his 1916 paper). Scerri, conversely, recommends adding a third sense to the concept of element, which he calls the 'combined simple substance'.

Both Mahootian, Llored, Restrepo and Ruthenberg seem to prefer a relational definition of the concept of element, although for different reasons. Hendry, finally, in a refreshing new take on the matter, seems to agree with Earley when he writes: "Given that 'simple substance' can be defined in terms of 'basic substance' (a simple substance is a substance composed of only one basic substance), there is nothing of interest, from a philosophical point of view, in the distinction" (p. 124). Instead, Hendry focusses on the superheavy elements. Since most of them are too short-lived to acquire a stable electronic structure, it is not clear whether these nuclear species can have chemistry, and whether they should count as chemical elements. Both Hendry and Restrepo therefore recommend adding a new criterium of existence, *viz.* having a lifetime of at least 10^{-14} s.

Conclusion

As is to be expected of a work published by Oxford University Press, *What Is A Chemical Element?* is written by scholars for scholars. In view of its content, it is primarily for philosophers and historians, and only secondarily for educators and chemists. Interested college students, teachers and/or laymen may find some of the chapters a daunting read. As Kragh (2021, 158), in

his review of the same book, beautifully observes: “For better or for worse, it illustrates how philosophy of chemistry has come of age as an independent branch of academic philosophy of science. With the independence follows almost inevitably a specialized academic language and a scholarly style that makes the new research area uninviting or even slightly incomprehensible to outsiders.”

Ideally, an edited volume should be more than the sum of its parts, at least to the reviewer’s mind. While the presentation of numerous fresh perspectives on a particular subject matter is undoubtedly worth the effort, it is only by drawing connections between them (highlighting points of convergence and divergence) that the field can truly advance. Having said that, given the diversity and consistently high quality of the essays, everyone will find something of interest in this volume. Although the reader may not find a definite answer to the title question—despite its apparent simplicity—he/she will certainly walk away with a deeper appreciation of this central question in philosophy of chemistry.

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