# BOOK REVIEWS

*What Is a Chemical Element? A Collection of Essays by Chemists, Philosophers, Historians, and Educators*, Eric Scerri and Elena Ghibaudi, Eds., Oxford University Press, 2020, ix + 296 pp, ISBN 978-0-19-093378-4, $99.95 (hardcover).

The concept of a chemical element is used by all practitioners of chemistry, from beginning students to professional researchers. Given this, it may surprise many chemists to consider the ambiguities in its definition, reflected in the fact that the IUPAC definition of "element" is itself twofold, with its two parts (types of atoms *versus* pure elemental substances) related but clearly different. The editors of this volume, Eric R. Scerri of UCLA and Elena Ghibaudi of the University of Torino, have assembled an eclectic combination of papers discussing the history of the concept of chemical element, especially its varying formulations in microscopic, atomist terms *versus* its definition by Antoine Lavoisier as a substance that cannot be decomposed further by laboratory operations, the philosophical questions raised by these disparate definitions, and their implications in chemical education.

Chapter 1 (The Many Questions Raised by the Dual Concept of "Element"), by Eric R. Scerri, serves as an introduction to and stage-setting for the remaining essays in the book, by illustrating philosophical questions in chemistry that many practicing chemists may not have considered. Scerri discusses the problems raised by the current, dual IUPAC definition of "element," and relates them to Dmitri Mendeleev's idea of a property of elements that persists through chemical transformations, and to Friedrich Paneth's dual concepts of *einfacher Stoff* ("simple substance") and *Grundstoff* ("basic substance"), a duality that inspired IUPAC's current definition. He then discusses a proposed modification of Paneth's definition that relates a "basic substance" to both elementary and compound bulk substances, and applies concepts relevant to the definition of "element" to the longstanding question of whether Group 3 of the Periodic Table should consist of Sc and Y followed by Lu and Lr or by La and Ac. The chapter concludes with an overview of what Scerri considers open questions on the topic.

Chapter 2 (From Simple Substance to Chemical Element), by Bernadette Bensaude-Vincent, discusses Lavoisier's operational definition of "element" as a substance incapable of undergoing additional decomposition, and the implication (recognized by Lavoisier) of this definition that substances currently recognized as elements may later be revealed to be compounds, should novel laboratory techniques be developed to effect their decomposition. Bensaude-Vincent argues that Lavoisier's stated desire to avoid metaphysical considerations of the fundamental components of matter by this operational definition were undermined by the fact that he still classified light and "caloric" (heat) as elements, despite the fact that neither can be isolated or handled as a distinct substance. She goes on to discuss Mendeleev's clear conception of "element" as including an abstract quality distinct from isolable elementary substances, and reviews his use of the atomism pioneered by John Dalton.

Chapter 3 (Dmitri Mendeleev's Concept of the Chemical Elements Prior to the Periodic Law), by Nathan M. Brooks, complements Bensaude-Vincent's essay with a detailed and fascinating historical perspective on Mendeleev's thought and views, including his undergraduate work on crystal isomorphism and his (unsuccessful) attempt to establish a "theory of limits" to explain the behavior of organic compounds. Brooks emphasizes Mendeleev's recognition of the persistence of a given element across allotropes, as exemplified by his insistence that the fundamental determinant of carbon (in his view, the atomic weight) was unaltered between coal and diamond, despite his skepticism of particular theories of atomic structure, such as the (incorrect) hypothesis of William Prout according to which hydrogen was the fundamental building block of atoms of other elements.

Chapter 4 (Referring to Chemical Elements and Compounds: Colorless Airs in Late-Eighteenth-Century Chemical Practice), by Geoffrey Blumenthal, James Ladyman, and Vanessa Seifert, discusses the naming of substances in the eighteenth century before the work of Lavoisier and modern (or quasi-modern) concepts of elements. In particular, the authors focus on the terms used to describe various gaseous substances ("airs"), such as "acid air" (HCl), "fixed air" ($CO_2$), and "phlogisticated air" ($N_2$). An historical discussion of such reference terms is followed by the proposal of a causal-descriptive theory of reference for substances.

Chapter 5 (The Changing Relation between Atomicity and Elementarity: From Lavoisier to Dalton), by Marina P. Banchetti-Robino, begins with a historical overview of concepts of elements used by ancient Greek philosophers and medieval scholars, in particular the Aristotelian concept of hylomorphism, according to which a substance (*ousia*) is defined both by its matter (*hylē*) and form (*morphē*). Banchetti-Robino continues with a discussion of the rejection of hylomorphism by early modern "chymists" such as Daniel Sennert, and the adoption of Epicurus-inspired early forms of mechanistic atomism by scientists such as Pierre Gassendi and Robert Boyle. This is followed by a description of the contrasting schools of thought of Lavoisier, who wished to avoid the "metaphysics" of speculations about atomic composition and structure, and Dalton, whose conception of atoms and use of this picture to explain Joseph Proust's law of definite proportions continues to underlie (with considerable modifications) modern chemistry. The chapter concludes with a discussion of some of the imperfections in Dalton's theory and their later modifications.

Chapter 6 (Origins of the Ambiguity of the Current Definition of Chemical Element), by Joseph E. Earley, begins with an overview and comparison of the historical concepts of elements: the ancient Greek view, Lavoisier's definition in terms of substances that cannot be decomposed, Mendeleev's view that elements are components of substances that determine their properties, and the view of elements as composites, based on the existence of allotropes and isotopes. Earley goes on to criticize the common translation of Paneth's concept of *Grundstoff* as "simple substance," arguing that the importance of the *Grundstoff* idea is that it does *not* refer to a substance *per se*, and that viewing it as a substance leads to the IUPAC's current ambiguity and (partial) acceptance of a Lavoisier-like view of elements as simple substances such as $N_2$, $O_2$, or bulk metals. He concludes the chapter with a proposal that chemists and philosophers view elements as those principles whose interaction leads to coherence and emergence of new entities (substances), and proposes a definition of such emergence in terms of formal logic.

Chapter 7 (The Existence of Elements, and the Elements of Existence), by Robin Findlay Hendry, addresses the challenges posed to traditional definition of "element" by the synthesis of "superheavy elements" (SHEs) whose nuclei have extremely short lifetimes. In particular, Hendry raises the question of whether the existence of an isolated nucleus with a particular atomic number $Z$—commonly used to define an element—is sufficient if said nucleus decays on a time scale faster than that required for it to collect its complement of electrons. That is, if chemistry is defined by the loss, gain, or sharing of electrons between nuclei, a nucleus too short-lived to obtain a stable electronic structure may have no "chemistry" at all. He then considers these concerns in light of the "special composition question" (SCQ) of composite objects, and proposes a "moderate" answer to the SCQ for elements, in which the conditions necessary for the existence of the composite object (an element) are not universally applicable.

Chapter 8 (Kant, Cassirer, and the Idea of Chemical Element), by Farzad Mahootian, applies the ideas of Immanuel Kant and Ernst Cassirer to the definition of "element." Mahootian focuses on Kantian concepts of perception and experience, and Kant's own profound interest in chemistry, in particular Kant's idea that the atom is a *focus imaginarius* or "ideal source," which should not be considered as a real object, but which can be viewed as a useful source of principles for describing the real world. He then considers the post-Kantian philosophy of Cassirer in relation to mathematical approaches to chemistry and Joachim Schummer's idea of the "chemical core of chemistry."

Chapter 9 (The Operational Definition of the Elements: A Philosophical Reappraisal), by Joachim Schummer, reexamines Lavoisier's "operational" definition of "element" as undecomposable substance, and argues that this definition and its intellectual milieu should be viewed as a "chemical revolution" analogous to the later revolutions of modern physics. While Lavoisier's definition of "element" lacks explanatory power compared to atomist views informed by quantum mechanics, in a pre-quantum context it represented a shift from metaphysical ideas of a strictly limited number of elements (as argued by ancient philosophers and medieval alchemists) to a focus on substances practically accessible by human activity. Schummer argues that this change in focus was crucial for the experimental work underlying much of modern chemistry. He goes on to discuss "operational" definitions of "element" in light of Horace Romano (Rom) Harré's ideas of realism, and how the IUPAC's twofold definitions of "element" relate to the conceptions of Islamic Golden Age philosophers Ibn Sina (Avicenna) and Ibn Rushd (Averroes).

Chapter 10 (Substance and Function: The Case of Chemical Elements), by Jean-Pierre Llored, examines the apparent conflict between the centrality of change to chemistry and the requirement that elements represent a principle unchanged in chemical reactions. Llored applies mereology to a variety of chemical questions, including the philosophical questions relevant both to experimental achievements such as the syntheses of organometallic and non-stoichiometric compounds and to theoretical strategies such as Richard Bader's quantum theory of atoms in molecules (QTAIM).

Chapter 11 (Making Elements), by Klaus Ruthenberg, serves as an interesting complement to Schummer's essay, in that it examines various attempts to understand "elements" based on empirical description, as opposed to the measurement of atomic number—a measurement that few practicing chemists actually do. In particular, Ruthenberg discusses the attempts of František Wald and Wilhelm Ostwald to develop purely empirical forms of chemistry and their failures, such as Ostwald's insistence that different sciences should be considered to have their own types of energy, or even that each separate element has its own energy. He criticizes the common distinction drawn between "synthetic" and "analytical" chemistry, noting that the isolations of elements, while often viewed as "analytic" procedures, are in fact instances of chemical synthesis, and that modern analytical chemistry usually involves a significant amount of sample preparation. He concludes the chapter by discussing the "synthetic," in a different sense, related to the nature of the practice of nuclear chemistry with its creation of new elements.

Chapter 12 (A Formal Approach to the Conceptual Development of Chemical Element), by Guillermo Restrepo, uses formal logic to develop a series of possible definitions of chemical element based on reactions, beginning with the operational definition of Lavoisier and modifying this based on considerations of atomic weight, atomic number, and nuclear lifetime (echoing the concerns of Hendry presented elsewhere in the volume). Restrepo then discusses chemical elements and chemical reactions according to Bernhard Ganter and Rudolf Wille's methodology of formal concept analysis (FCA). The chapter concludes with an argument that the necessary and sufficient conditions for chemical element-hood should be (1) an atomic number, (thus meaning that electrons, positrons, and photons are not examples of elemental species, and (2) participation in chemical reactions, where reactions are taken to include van der Waals interactions, thus including as elements those noble gases not known to form "compounds" in the traditional sense but excluding from element-hood SHEs whose nuclear lifetimes are too short to acquire electrons.

Chapter 13 (Chemical Elements and Chemical Substances: Rethinking Paneth's Distinction), by Sarah N. Hijmans, explores Paneth's dual definition of an element as both a stable elementary substance and as a metaphysical "basic substance," a dichotomy that persists, in a modified form, in the current IUPAC definition. Hijmans discusses Scerri's modified definition, in which basic substances underlie elemental bulk substances and compounds alike, as an improvement to such a dichotomy, but notes that this modification retains mutually exclusive definitions of "element." Following this critique, she argues that post-Lavoisier definitions of "element" that moved beyond the undecomposability criterion frequently viewed the principle that remains unchanged in chemical reactions not as abstract or metaphysical, but rather as physical and material, albeit microscopic. The chapter concludes with a proposal that instead of a dualistic definition of "element," chemical elements instead should be thought of as a single concept with both theoretical and empirical aspects.

Chapter 14 (The Dual Conception of the Chemical Element: Epistemic Aspects and Implications for Chemical Education), by Elena Ghibaudi, Alberto Regis, and Ezio Roletto, discusses the confusion to which beginning chemistry students are vulnerable as a result of unclear definitions of "element." The use of "elements" to describe elemental substances such as $O_2$ invites confusion, since students are taught that elements are conserved in chemical reactions, yet the chemical species $O_2$ is clearly not conserved in a combustion reaction. Similarly, when students are introduced to elements and their chemical symbols as a mere ordering or classification of different kinds of atom, it obscures the theoretical basis for the

Periodic Table and its utility for predicting, as Mendeleev did, the properties of elements yet to be discovered in the Table's empty spaces. The authors reject any simple identification of "elements" with simple substances, atoms, or nuclei, and instead propose a consistent definition of element that applies at both the macroscopic and microscopic levels.

The essays in this book examine the concept of "element" from a variety of schools of thought, and they should prove interesting and informative to philosophers and historians of science in addition to practicing scientists (especially chemists) with a philosophical bent. While the level of background knowledge assumed on the part of the reader varies from essay to essay, for the most part the authors do a commendable job of illustrating the historical and philosophical points using chemical concepts that should be understandable to anyone who has completed a first-year undergraduate chemistry course. Similarly, most philosophical concepts used, with the exception of the notation of formal logic in Chapters 6 and 12, are explained for the benefit of readers trained in natural science but not academic philosophy. The book is thus suitable for readers with a wide range of interests and academic backgrounds, and will surely stimulate many useful further discussions and debates.

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*Robert Le Rossignol: Engineer of the Haber Process,* Deri Sheppard, Springer Biographies, Cham, Switzerland, 2020, xxiii, 547 pp, ISBN 978-3-030-29714-5, $97.

As I write these lines, it is clear that all of us have witnessed one of the most astounding accomplishments ever in medicine. A world-wide pandemic surfaced in January 2020, and in an approximately ten-month interval multiple vaccines for Covid-19 were discovered, developed, and brought into distribution to the public, with other vaccines now following. This astonishing result came about because of strong cooperation among government, industry, and academia. Whenever the scientific accomplishments of the 21$^{st}$ century are listed, this development of Covid-19 vaccines has to rise to the top of the list.

What are the great accomplishments of the century just past, the 20$^{th}$ century? Perhaps the most important was the discovery of artificial nitrogen fixation in the early years of that century. Nitrogen based fertilizers were vital for food production for an ever growing world population, but the supply of nitrate fertilizer from natural sources in South America was under increasing pressure. At the beginning of the 20$^{th}$ century, starvation of millions was not that many years away. This was highlighted by English scientist Sir William Crookes in an 1898 speech to the British Association for the Advancement of Science. Crookes also proposed the solution—converting the nitrogen in the air to nitrogen based fertilizer. However, this was far more easy to propose than to actually accomplish.

You readers know that artificial fixation of nitrogen did in fact take place in the first decade of the 20$^{th}$ century. HIST recently recognized the accomplishment with one of its Citation for Chemical Breakthrough Awards. The name that all associate with this accomplishment is that of German chemist Fritz Haber. Those with a little more knowledge would add the name of Carl Bosch. Haber's synthesis of ammonia by catalytically reacting hydrogen with nitrogen was vital, but the scale up of the synthesis for industrial use was accomplished by German engineer Bosch. Both individuals were Nobel Prize winners for