Women in Their Element: Selected Women's Contributions to the Periodic System, Annette Lykknes and Brigitte Van Tiggelen, eds., World Scientific, New Jersey, London, 2019, xxiv + 531 pp, ISBN 978-981-120-628-3, $128; 978-981-120-768-6, $45 (softcover), 978-981-120-630-6, $19.90 (ebook).

Despite the fact that this volume was developed as one of the core initiatives of the European Chemical Society (EuChemS), in celebration of the International Year of the Periodic Table 2019 (IYPT2019), the many contributors to the 38 women-featured chapters, in a true international spirit, hail from very disparate places: 23 from nine different European countries, 8 from North America, and one each from Australia and Japan. Pilar Goya, the 2019 President of the EuChemS, acknowledged in her foreword to the volume that women had, at best, complicated and limited access to scientific investigation, but were often discouraged, discriminated against, and denied access simply on the basis of their gender. Natalia Tarasova, Co-Chair of the IYPT2019 Management Committee and Past-President of the IUPAC, seconds this assessment in her own foreword by advocating that structural issues and legal frameworks that present barriers to women's empowerment be dismantled and that those promoting gender equality be advanced. She cited the fact that chemistry has had a long and honorable tradition of participation by highly creative women but that the percentages of women scientists remain shockingly low. She sees the celebration of IYPT2019 and its aftermath as an extraordinary opportunity to right these wrongs and to promote science education for all women at every level, particularly in developing countries.

The editors, Annette Lykknes, of the Norwegian University of Science and Technology, Trondheim, and Brigitte Van Tiggelen, of Mémosciences, Louvain-la-neuve, Belgium and the Science History Institute, Philadelphia, USA, present us with a brief preface (6 pages) and a very lengthy introduction (54 pages!). In the former, they speak of the target readership for the volume: science-curious adults with a taste for history, as well as professional historians of science. They provide reference lists and bibliographies to satisfy the professionals, but in such a way as to not overwhelm the merely curious. The authorship of the chapters was deliberately drawn from many different disciplines to represent the community at large. They remind us that when Mendeleev devised his system (and they deliberately use *system*, not table), there were still many chemists who did not believe that atoms really existed. Yet, over the centuries, there was a continued effort to understand the elements and to grapple with the complexity presented by the periodic system. Though the pathway was not smooth, this volume, by design, documents an uninterrupted progression from the twilight of alchemy to the discovery of the superheavy elements. The major section of this introduction is titled, and appropriately so, "Women Discovering and Mastering Elements." Subdivisions summarize women's roles in the discovery of artificial radioactivity and the synthesis of the superheavy elements, their move into the development and use of advanced analytical methods, and their ever-present awareness of the social implications of "big science." Male leaders who provided opportunities for women scientists by mentoring, collegial recognition, providing a welcoming and friendly atmosphere, and promoting an egalitarian attitude in the profession are mentioned, among them Dmitri Mendeleev (1834-1907), Ernest Rutherford (1871-1937), and Harold Urey (1893-1981). While not every scientist who did so could be listed, curiously, three outstanding leaders who welcomed women into their research groups when it was still fashionable to criticize them for this practice, were omitted: William Henry Bragg (1862-1942), William Lawrence Bragg (1890-1971), and F. Gowland Hopkins (1861-1947). In closing the introduction, the editors note that the 38 vignettes of women scientists that comprise the book are as diverse as the elements in the periodic system itself; much of the information contained in the volume is based not only on written documents, but, whenever possible, on interviews and oral histories.

In Part 1, "Old and New Understandings of the Elements," three women are featured: Dorothea Juliana Fischer Wallich (1657-1725), Marquise Émilie Du Châtelet, née Gabrielle Émilie le Tonnelier de Breteuil (1706-1749) and Marie-Anne Pierette Paulze-Lavoisier (1758-1836). All three, whose lifetimes span almost two centuries, were very different in their approaches to and interests in science. Wallich was held in high esteem by Georg Ernst Stahl (1659-1734), developer of the phlogiston theory, for her ability to extract silver from its ores. She published three books in the years 1705-1706 describing her work with "minera," a putative precursor of the philosopher's stone. In the course of her experiments, which involved treating this substance, which we now infer was native bismuth mixed with some cobalt compounds, with nitric acid, she produced impure cobalt(II) chloride. (Cobalt was only discovered and recognized as an element in 1735, ten years after Wallich's death.) She subsequently noted the thermochromic effects of the latter, interpreting them as a step along the way toward discovering the philosopher's stone. If she had concentrated on the chemistry involved instead of the

alchemy, she may have been the first woman to discover an element. Our second proto-chemist in this section is Madame Du Châtelet, a woman who was obsessed with defining the nature of fire. An experimentalist who concentrated on fire's properties, including light, color, and heat, she published a dissertation on this topic, replete with faithfully recorded original observations, in 1744. Endowed with a lively curiosity and unbiased spirit, she was in the midst of writing a French exposition of Isaac Newton's (1643-1727) ideas when she died in childbirth in 1749. Her various works, which actually dealt with inchoate fields such as thermodynamics and the nature of energy, incorporated thinking that was far ahead of her time. Marie Paulze-Lavoisier is best remembered as a para-scientist since she worked side-by-side with her husband, Antoine-Laurent Lavoisier (1743-1794)—painting, drawing, describing his experiments; translating the ideas of others; and disseminating the anti-phlogiston ideas of the Chemical Revolution. She studied and absorbed the new ideas and nomenclature of her husband and his colleagues to such a degree that she was able to write not just a translation of the phlogistic ideas of Richard Kirwan (1733-1812), but a definite counter-attack that promoted Lavoisier's oxygen theory. She was an important protagonist in ushering in the dawn of quantitative chemistry.

Part 2, "The Glory of Analytical Chemistry: The Elements Multiply," contains seven chapters. Four of them highlight the contributions of individuals: Jane Haldeman Marcet (1769-1858), Julia Lermontova (1846/47-1919), Astrid Cleve Von Euler (1875-1968), and Ellen Swallow Richards (1842-1911). Each of these four women was remarkable in her own right. Jane Marcet's very popular book, *Conversations on Chemistry*, was an intercontinental phenomenon, with tens of thousands of copies printed through many editions, each of which was meticulously updated to contain the latest discoveries personally collected by the author from the actual scientists themselves. Though she had no formal training in science herself, Marcet gleaned and repackaged cutting edge science from informal meetings, meticulous lecture notes, experiments done at home in company of her husband, Alexander (1770-1822), contact with leading scientists, and access to books and journals. An early edition of her book is what enticed Michael Faraday (1791-1867) into science when he read it as a bookbinder's apprentice. (A series of articles in *This Journal* traces the evolution of the various editions of *Conversations on Chemistry* in detail.) Julia Lermontova made a substantial contribution to separation and atomic weight determinations of the platinum metals. Astrid Cleve Von Euler's book, *The Wonderful Element Selenium*, served to popularize science by its unusual style: the use of simple metaphors to make abstract concepts understandable. However, during her marriage she found that her time was to be made entirely at her husband's disposal, and after her divorce, she found herself, tragically, without a home, a laboratory, and an income. Ellen Swallow Richards was the first woman to enroll at MIT; she is best known for her efforts to promote science for the common good, thus becoming an activist for women's education and for a healthy environment. She put her chemistry to work by doing the major portion of the analytical work on the study of industrial pollution of Massachusetts waterways. Three other chapters in this part review (a) the contribution of women analysts whose work helped map the different elements in the periodic table, (b) the work of three Spanish women scientists in fluorine chemistry and (c) the contributions of four women chemists to the chemical literature of the elements.

Part 3, "New Fields and Instrumental Methods," highlights the contributions of six outstanding women to the evolution of the periodic table. They are Clara Immerwahr Haber (1870-1915), Cecilia Payne-Gaposchkin (1900-1979), Ida Tacke Noddack (1896-1978), Erika Cremer (1900-1996), Dame Kathleen Yardley Lonsdale (1903-1971) and Yvette Cauchois (1908-1999). Clara Immerwahr Haber's collaborative work with Richard Abegg (1869-1910) broadened and clarified the concept of electronegativity, although her later life with Fritz Haber (1868-1934) led to grief and her eventual suicide. Astronomer Cecilia Payne-Gaposchkin, a specialist in the study of stellar spectra, was the first person to recognize the true composition of the stars, mainly hydrogen and helium. Ida Tacke Noddack is famous for two reasons: her co-discovery of the element rhenium, and her 1934 hypothesis that shook the scientific world (belatedly): "When heavy nuclei are bombarded by neutrons, it is conceivable that the nucleus breaks up into several large fragments..." This first-ever proposal of nuclear fission went ignored, and even ridiculed, by the scientific community which was unprepared to imagine a process unsubstantiated by theory. Erika Cremer was the first person to apply quantum tunneling theory to heterogeneous catalysis; she also pioneered the new analytical technique of gas-solid chromatography. Dame Kathleen Yardley Lonsdale, a crystallographer whose mentor was William Henry Bragg, confirmed the planar structure of benzene, thus enabling the evolution of modern organic chemistry. Yvette Cauchois' major contribution to science was the development of her eponymous curved-crystal spectrograph that improved luminosity and resolving

power, making it possible to observe spectral lines never seen before. This invention enabled the measurement of the low intensity X-ray emission lines typical of rare earths, rare gases and heavy elements.

Part 4, "Clusters of Women in Radioactivity," begins, naturally, with a chapter on Marie Skłodowska Curie (1867-1934) of whom so much has been written that it is unnecessary to add to that mountain of information at this point, except that the author observes that her life and career are testimony to the importance of family support and the careful management of a personal and a professional life. Nine additional chapters highlight the lives of ten additional women, none of whom have the iconic celebrity traction of Marie Curie except, perhaps, Lise Meitner (1878-1968), who now "inhabits" the periodic table as meitnerium. Meitner, next to Curie, has been acknowledged as one of the greatest women scientists (perhaps, greatest without the "women" appellation?) of the twentieth century; her long career exemplifies the difficulties of a life in science, but also the ways in which women sought and managed to overcome them. Other women in the "radioactivity club" are Harriet Brooks Pitcher (1876-1933), who worked with Ernest Rutherford on the discovery of "emanation," later found to be the element radon; Dr. Margaret Todd (1859-1918), a physician who coined the word "isotope" for Frederick Soddy (1877-1956), though it went unacknowledged by him; Stefanie Horovitz (1887-1942) who, by her very precise measurements, provided the first authoritative evidence for the concept of isotopes; Ellen Gleditsch (1879-1968), whose most celebrated achievement was the exact determination of the half-life of radium; May Sybil Leslie Burr (1887-1937), whose experiments with thorium emanation helped clarify the process of radioactive decay and the nature of the decay products; Elizabeth Róna (1890-1991), who became the world's leading expert on polonium, crossing the borders between chemistry, physics, biology and medicine for most of her career; Marguerite Perey (1909-1975), who discovered francium (element 87), the last element that could be extracted chemically from minerals, and the Austrian duo, Berta Karlik (1904-1990) and Traude Bernert (1915-1998), who discovered the isotopes 215, 216, and 218 of element 85, formerly "eka-iodine," known today as astatine—the rarest naturally occurring element on earth.

The final three parts, "Manufacturing Elements: From Artificial Radioactivity to Big Science," "Instrumental Revolution and Interface Between Chemistry and Industry," and "Social Activism, Sisters in Arms" (parts 5, 6, and 7 respectively) bring us into the modern era—complete with several color photographs. Beginning with the discovery of artificial radioactivity by Irène Joliot-Curie (1897-1956) and her husband, Frédéric (1900-1958), an event that led to greater understanding of nuclear processes and the production of the transuranics, Part 5 documents the role of Isabella Lugoski Karle (1921-2017) in plutonium research, Chien-Shiung Wu's (1912-1997) identification of Xe-135 as the "nuclear poison" that kept shutting down nuclear reactors, Darleane Christian Hoffman's (b. 1926) role in pioneering "atom-at-a-time" chemistry as the leader of the Heavy Element Nuclear and Radiochemistry Group at the University of California at Berkeley, and, following in Hoffman's footsteps, Dawn Shaughnessy's (b. 1972) collaborative work in identifying six superheavy elements as the group leader at the Lawrence Livermore National Laboratory. Part 6 examines instrumentation's role in cementing the relationship between chemistry and industry. Five women are featured in this part: Sonja Smith-Meyer Hoel (1920-2004), whose work in the Norwegian metals industry and patent system boosted her country's postwar recovery; Toshiko Kuki Mayeda (1923-2004), whose mass spectrometric expertise helped establish methods to use oxygen isotopes to study the history of the solar system; Mary Almond Pickering (b. 1928), whose paleomagnetism work provided the first-ever crucial step to confirming continental drift; Barbara Bowen (b. 1932), whose collection and digitization of atmospheric data led to the detection of the "ozone hole" over Antarctica; and Reatha Clark King (b. 1938) who, at the U.S. National Bureau of Standards (presently the National Institute of Standards and Technology), developed the apparatus and procedures to control and measure the combustion of dangerous gases that were later used as rocket propellants by the National Aeronautics and Space Administration (NASA). The women whose avowed vocation as social activists are highlighted in Part 7 include Gertrud Johanna Woker (1878-1968) who warned against the dangers of using tetraethyl lead as an anti-knock agent in automobiles as early as 1932 and warned against using scientific research for military purposes. Alice Hamilton, M.D., (1869-1970) had research interests in bacteriology, pathology and public health and social activist interests in the settlement house movement, which described its goals as residence, research and reform. These two thrusts eventually led her to become a pioneer of occupational epidemiology and industrial hygiene resulting in new legislation, new insurance requirements and modifications to industrial methods. An American Chemical Society National Historic Chemical Landmark (https://www.acs.org/content/acs/en/education/whatischemistry/

landmarks/alicehamilton.html) recognizes these contributions. And finally, we come to the formidable Ida Freund (1863-1914), the first woman to be appointed to a university lectureship in the UK. Through her books, Freund's impact remains strong to this day with respect to her educational ideas and the history of chemistry. Though she was a no-nonsense lady who deplored the association of chemistry with the kitchen, she nevertheless became famous for her whimsical promotion of the "periodic table of cupcakes" that became a staple of chemical education. In fact, this author and Sally Mitchell, Rye High School, Rye, NY, recently employed this same "hook" to draw students into an ACS New York Local Section Science Café called "Periodic Table People" during the #IYPT2019 (Figure 1).

Figure 1. Periodic Table of Cupcakes, momentarily intact. Periodic Table People Science Café, October 5, 2019, Saint John's University, Queens, NY. Photograph: Mary Virginia Orna

If you have managed to reach the end of this very long review, you no doubt realize that this volume is a rewarding exposition of the role of women in the development of chemistry, worthy of being read over and over again. Each reading reveals new riches and insights. One comes to understand that not only were women denied access to science for the reasons elaborated upon in the preface of this book, but in many other ways that were both systematic and the fruit of personal animosity, fear, and the simple opinion that women did "not count"—factors that come to light in many of the chapters in this volume. Among the former are the laws that many countries had in place that forbade women's entry into higher (and, in some cases that even persist today, to elementary) education. Among the latter, we note the failure of renowned scientists, among them Nobel laureates, to recognize the priority of women who preceded them or collaborated with them in their work, simply ignoring and yet building upon their ideas and publications—without any citation whatsoever. Perhaps the most egregious example of this behavior was that of Otto Hahn (1879-1968) who could possibly be excused from omitting Lise Meitner's name from their collaborative papers during the Nazi regime, but certainly cannot by failing to acknowledge her contribution to the discovery of fission after the war. Nowadays, we might find these individuals with intellectual property rights lawsuits on their hands. Another way of "putting down" these women was to simply dismiss their work as "not innovative" or "routine," missing the point that most research is apparently routine and not very innovative until a breakthrough occurs, the importance of which may dawn on the scientific community many years later because the work was ahead of its time. One very fine feature of the volume is that each chapter contains a rich set of endnotes and bibliography for further research. It is also completely indexed with a General Index, a Name Index, and an Element Index, and contains an appendix of authors' biographies (though without email addresses).

Some picky little errors: p. 71, 1749, not 1742, was the death-date of Madame Du Châtelet; pp. 101-111, Jane Marcet's book is variously referred to as *Conversations **on** Chemistry* and *Conversations **in** Chemistry*; and perhaps a dozen additional typos caught my eye. For a book numbering 531 pages, this is trivial!

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