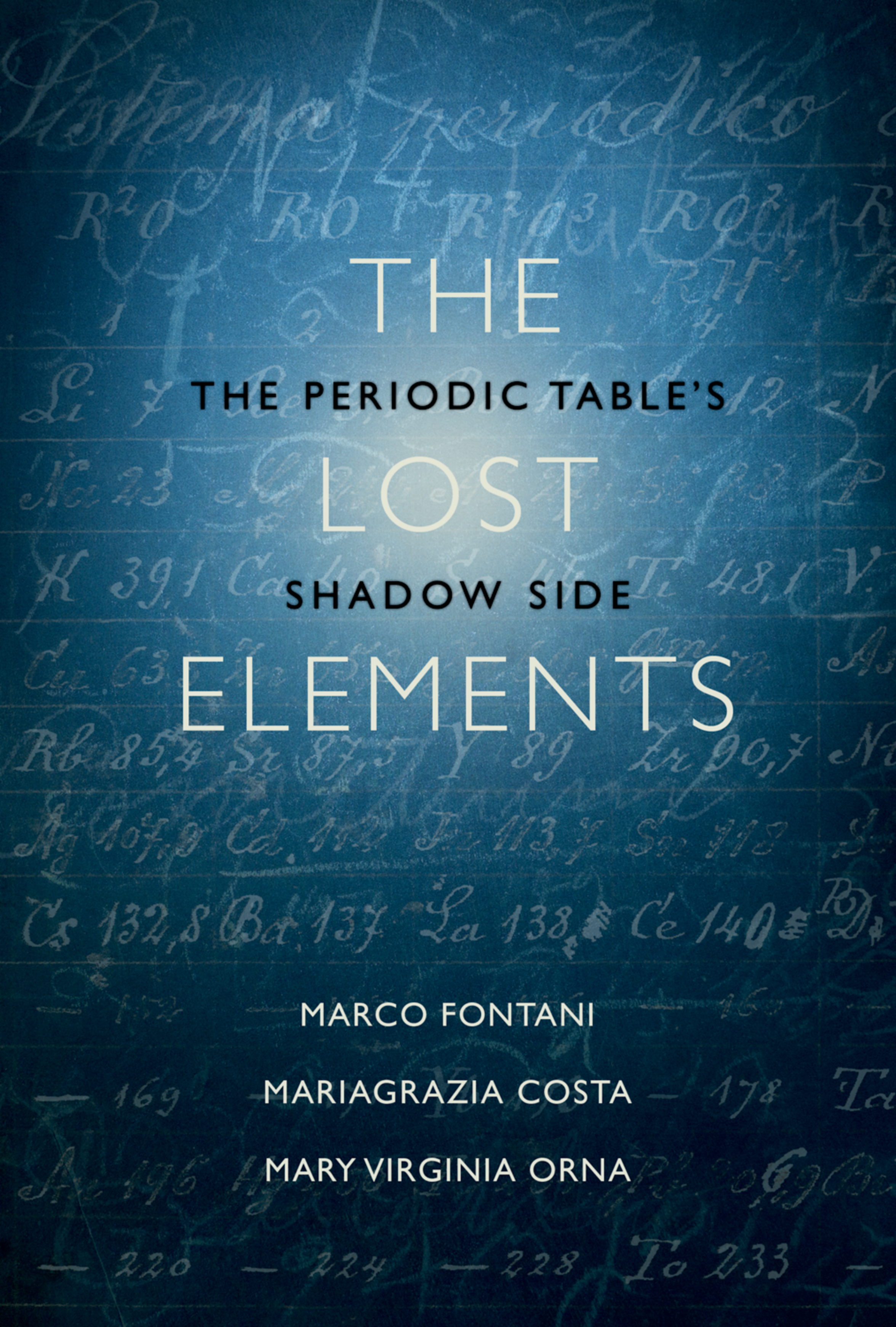

THE LOST ELEMENTS

THE PERIODIC TABLE'S SHADOW SIDE

MARCO FONTANI

MARIAGRAZIA COSTA

MARY VIRGINIA ORNA

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Marco Fontani, Mariagrazia Costa, and Mary Virginia Orna

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It is appropriate to recall the dedication
that, many years ago, I wrote on the manuscript of my bachelor’s thesis;
for this reason, I renew it with affection:
“To my parents: you were the lions; I have only roared.”
—Marco Fontani

To my beloved nephews,
may they all be attracted to Science.
—Mariagrazia Costa

To Maria Lucia (Grazia) Pulaccini,
my finest teacher and most beloved mentor.
—Mary Virginia Orna

ENTE CASSA DI RISPARMIO DI FIRENZE

CONTENTS

Part III: 1869–1913: From the Periodic Table to Moseley’s Law: Rips and Tears in Mendeleev’s Net

Part IV: 1914–1939: From Nuclear Classification to the First Accelerators: Chemists' Paradise Lost . . . (and Physicists' Paradise Regained)

Part V : 1939–Present: Beyond Uranium, to the Stars

PREFACE

I have not read as truly interesting a book as this one in decades—dip into it, open it on any page, and you are immediately drawn into a tale of human ambition, folly, and . . . ingenuity. Mostly chemical, too. Two pages later, there's another, even more fascinating story. Primo Levi would have loved this book. There is in it material for a dozen operas. Or is it reality shows?

Why? This question tugs at me. Why have chemists (and, in time, physicists) focused so much on the discovery of the elements? When the heart of chemistry, especially today, but even in the past, is in discovering the semi-infinite variety of molecules and compounds that they can form, why all this nervous energy and hard labor devoted to finding the building blocks, when the soaring bridge, mosquito, or antibiotic constructed from those pieces is so much more valuable, both materially and spiritually?

As I reflect on the obsessions that drove those people who sought what turned out to be spurious elements, who spent years at good chemistry (you will learn here of Lorenzo Fernandes's and Giorgio Piccardi's 56,142 fractional crystallizations of 1,200 kg of rare earth oxalates over 17 years in their search for *florentium*), I am led to think of the following potential motives:

1. The desire in us (both religious and scientific in its origins) to get to the beginning of things, to the fundamental *idea* of the element. Even if we know (or believe) that reductionism may be destructive in practice—that the way to the fundamental strips away the beauty of what people have created even though lacking knowledge of the fundamental—we really do want to know what "the natural body or bodies, one or many, of which all things consist" (Davis, 1931) are.
2. In his satire, "The Dunciad," Alexander Pope had the goddess of Dullness expose a new king to "vapours blue" and then tell him, inter alia:

> Hence the fool's Paradise, the statesman's scheme,
> The air-built castle, and the golden dream,
> The maid's romantic wish, the chemist's flame,
> And poet's vision of eternal fame.

Delusions of fame are the bane of humanity. I think of my old copy of what we called "The Rubber Book," the encyclopedia we saved money to buy volume by volume—these had simplistic, categorical attributions of discovery. As did handbooks of a 100 years ago. As do chemistry webpages today. How nice it would be to have your name in them! In the dull confines of a smelly laboratory, a scientist could aspire to embark on the chemical equivalent of the great European voyages of discovery.

And, if you found an element, you could also name it. Maybe it wouldn't seem so selfish then—maybe the name of your town or country would do nicely. A human weakness, one that shows no signs of abating in the 21st century.

3. What a challenge to the chemist's analytical prowess was the establishment of a new element! To isolate the tiny residue that is truly different, after many transformations wrought on it. Then to reduce it, in the old way, with hydrogen, to a speck of metal. Or, later, to look at its spectrum. The craftsmanship, the good hard chemical labor, in the service of a paradigmatic search for something new, pervaded the style of the inorganic chemists who searched for new elements. They could not yet see into the way the atoms were arranged in their compounds; their transformations were all they had. They were right to be proud of their skills.

In this lovingly researched book you have the dead ends, the voyages of discovery whose end is certain shipwreck. And you have here a superlative antidote to the hagiographical seduction of the stories, often just as complex in detail, of the reliable identification of new elements. Although some, such as Ramsay's wonderful identification of the noble gases, are retold here, these have been admirably recounted elsewhere. In "The Lost Elements," the failures speak to us. Completely lacking in the false condescension of "How stupid can you be?," the byways recounted in this book turn into lovely meandering paths, leading to an understanding of how chemistry really works.

—Roald Hoffmann

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In such a huge volume, it is impossible to remember adequately the enormous and largely hidden contributions of so many persons who, in conversations or with answers to our questions, have supplied information and suggested new lines of investigation.

Most importantly, this book has been produced with the financial support of Ente Cassa di Risparmio di Firenze (ECRF), Florence, Italy, for which the authors are sincerely grateful.

It has taken more than a dozen of years of hard work to bring this volume to fruition. It was not a continuous task, but definitely a difficult and exciting one. Over such a long period of time, many people were involved in our surveys, and if, in these official acknowledgments, someone has been omitted, we deeply apologize.

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The writing of the manuscript took so much time that one of the authors (Marco Fontani), soon after receiving his Ph.D., moved to the University of Florence, where he wishes to thank his new colleagues: Emily Bulukin, Chiara Carbonera, Piero Sarti-Fantoni, Ivano Bertini (1940–2012), and Paolo Manzelli. The personnel at the Polo Scientifico di Sesto Fiorentino Library, Sabina Cavicchi, Marzia Fiorini, Roberto Bongi, Laura Guarnieri, and Serena Terzani, and at the library of the College of New Rochelle, Carolyn Reid and Kathy Mannino, deserve special thanks; they were able to find, with indomitable enthusiasm, all the material we needed, overcoming the numerous difficulties created by so many and such unusual requests.

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NOTE TO THE READER

This book is divided into seven sections, arranged largely chronologically.

Part I consists of announcements of discoveries that precede the formulation of the concept of "chemical element" in 1789, the conventional date that coincides with the publication of the "Traité Élémentaire de Chimie" by Antoine Lavoisier, which is considered the first modern treatise on chemistry.

Part II embraces the period from 1789 to 1869, the date of Dmitri Mendeleev's formulation of the periodic table of the elements.

Part III ends at the very beginning of World War I (1914), a period of relative elemental chaos, with research following the guiding logic of Mendeleev's empirical organizing principle but lacking a theoretical basis.

Part IV (1914–39) takes us through Moseley's revolution and Soddy's isotopic theory, to the advent of the synthesis of new nuclides with the aid of the first linear accelerators and cyclotrons.

Part V takes us up to the present day and consists largely of the syntheses of the transuranium elements, but also includes fanciful and imaginative stories of elusive elements whose atomic numbers were less than one ("heaps" of neutrons).

Part VI is devoted to those elements so bizarre that, if they had ever been discovered, they would never have found a place in the periodic table.

Part VII is dedicated to the most recent attempts at chemical transmutation, not in the alchemical sense, whose history would lead us far from the aim of this volume, but with physical instruments or cumbersome apparatus whose use was carried on in a "better way to obtain erroneous results."

Elemental names appearing in italics throughout the book are those of chemical elements that were false, spurious, not confirmed, or even correct but that have fallen into oblivion or whose use has been lost or changed over time. They occupy a separate index at the end of this volume.

A word about units: The units used in this book are the standard international units but, where appropriate, units mentioned in the original documents but no longer in use are also reported. A word about the persons who appear in this book: For those persons whose scientific discoveries are pertinent to the narration, a fairly extended biography is supplied. Birth and death dates (when known) are contained in the Name Index at the end of this volume and follow the person's name when first mentioned in the book.

INTRODUCTION

WHY COLLECT INTO ONE VOLUME THE DISCOVERIES OF ELEMENTS THAT HAVE BEEN SHOWN TO BE ERRONEOUS OR HAVE BEEN FORGOTTEN?

In 1961, Denis Duveen asserted that we cannot properly understand chemistry without a knowledge of its history.[1] This idea has subsequently been enlarged upon in the literature of chemical education. Its history "is not only a chronologically organized set of facts, but also a coherent picture of the origins of ideas, their development, and their influence and consequences for human civilization,"[2] and an aid to understanding how chemists have solved problems in the past, thus revealing the nature of the scientific process.[3] It is hoped that the contents of this volume will help readers understand that the pathway to the classification of the elements was fraught with obstacles and errors that actually, in the long run, helped to clarify the nature of these fundamental units of matter. One might even attribute the role of catalyst to some of these errors, in much the same way that the famous, but brilliant, blunders of Charles Darwin (1809–82), Linus Pauling (1901–94), and Albert Einstein (1879–1955) have become the stuff of legend.[4]

Although physicists have as their purview the birth of the universe, and biologists concentrate on the origin of life, chemists have a unique role to play in the ordering of the building blocks of nature, namely, the development of the periodic table of the elements. This single document embodies much of our knowledge of chemistry and, as such, has become emblematic of our discipline. However, the table as it has come down to us has undergone many changes over the two centuries of its evolution. Although certain relationships were initially discerned among the elements, how to order them was not always clear. An order based on atomic weight seemed to present the best approach in the mid-19th century, but many atomic weights had been determined erroneously, and, in addition, some anomalies in the properties of elements were observed. So it gradually became clear that there were missing pieces to the puzzle that had to be found. As well, the ordering attempt revealed some obvious gaps that led chemists to seek the missing elements—an enterprise that was notably successful.

And perhaps too successful—because once chemists realized that there were elements "out there" to be discovered, it was open season with no limits, particularly when it came to the higher atomic weight elements. It was only with the establishment of the atomic number as the primary ordering principle in 1913 that some "sense" could be made of the table. Yet, at the same time, the discovery of radioactivity and the seemingly endless "new" elements that made their appearance in research laboratories only served to create more confusion in what belonged and what did not belong in the periodic table.

Although today's periodic table presently comprises 118 elements, 114 of which bear definitive names, over the many decades of its creation this was not always so. In fact, there are many more elemental "discoveries" later shown to be false than there are entries in the present table. Some of these were good-faith errors, some were the result of personal wishful thinking, some were the fantasy children of pseudoscientists—and all have their fascinating stories that serve to illustrate the fact that our present knowledge came about in fits and starts, with many dead ends, regrettable personal and political battles, and sad retractions.

This fascinating journey, one that predates Dmitri Mendeleev (1834–1907) by several centuries, is what prompted us to write this book. Gathering the stories and the documentation of these erroneous, spurious, nonexistent "lost elements" into one place is our attempt to faithfully reconstruct the "scene of the crimes," so to speak. It should be borne in mind that many of the elements presently familiar to us did not have the same names that we use today: names that fell into oblivion were often the result of false claims and priority struggles. Other false elements actually occupied space in the periodic table as temporary "tenants" until they were proven false. The trail we have chosen to embark on is not exactly a beaten path, which is why it has taken the authors 14 years to collect and filter the material for this volume. It was first necessary to trace the history of the concept of the element, how elements were eventually defined, and then how scientists went about identifying them. The latter endeavors are documented mainly from primary sources.

With these premises, our book was born. We have written it as an informative and sometimes anecdotal compendium of the shadow side of the chemical elements, mirroring the tenacious dedication of Mary Elvira Weeks[5] (1892–1975) to the bright side of their discoveries. We feel that this effort is important because if we accept the premise that the history of science is not a collection of information but a tool to analyze that information and arrive at valuable conclusions,[6] then we offer this volume as an analytical tool to anyone who wishes to use it to develop research ideas and to draw helpful and valuable conclusions.

Finally, we would like to mention a popular website dedicated to the elements, http://elements.vanderkrogt.net/, an endeavor different from, but parallel to, our own. Both projects developed side by side over the past decade, and much of our own work was shared with and acknowledged by the developer of the website. On this site, you will also find the names of false elements, but only for those that eventually became attached to elements presently in the periodic table.

HOW "AN ELEMENT" BECAME A "CHEMICAL ELEMENT"

Before the modern model of the atom evolved, the concept of an element had been purely speculative. Aristotle (ca. 382–22 BCE), one of the greatest philosophers of antiquity, theorized on the nature of what he called principals, elements, substances, and numbers, frequently interweaving all four in a complex philosophical dance. Drawing on the writings of others, he said "Empedocles . . . was the first to speak of four material elements; yet he does not use four, but treats them as two only; he treats fire by itself, and its opposite—earth, air, and water—as one kind of thing," and again, "[Leucippus and Democritus] say the differences in the elements are the causes of all other qualities."[7] He enlarged on these ideas thus: "the elements out of which . . . units are said to be made are indivisible parts of plurality" and "everything that consists of elements is composite."[8] Aristotle's teaching was the theoretical foundation of alchemy and of various Western schools of natural philosophy for many centuries thereafter.

In contrast to the Aristotelian idea of earth, air, fire, and water comprising the four elements, early Chinese naturalists centered on five: earth, wood, metal, fire, and water—not so much as five types of fundamental matter, but as five ways in which matter was fundamentally related through process and only manifest when they were undergoing change.[9] This idea of change as a necessary property of matter presages, although not in so many words, the entire basis of the discipline of chemistry.

In the 16th century, Aureolus Philippus Theophrastus of Hohenheim, called Paracelsus (1493–1541), a famous physician and scientist, brought the elements "down to earth." Still believing in the four elements,[10] he introduced the idea that on another, spiritual level, all substances consist of three sources: mercury, salt, and sulphur, which are the carriers of three qualities—volatility, solidity, and inflammability.[11] Clues to a proper understanding of the nature of elements can be found in the teaching of Robert Boyle (1627–91), an outstanding 17th-century English chemist. In his book *The Sceptical Chymist*, Boyle criticized the view of elements as carriers of certain qualities. Elements, according to Boyle, must be material in their nature and constitute solid bodies. He contended that mere theoretical examination, without experiment, was quite insufficient, remarking with a stiff dose of sarcasm that "when I took the pains impartially to examine the bodies themselves that are said to result from the blended Elements, and to torture them into a confession of their constituent Principles, I was quickly induc'd to think that the number of the Elements has been contended about by Philosophers with more earnestness then [sic] success."[12] Boyle, although admitting that he had no effective system to offer in place of the philosophies that he attacked,[13] also spoke against the belief that the number of elements is limited, thus opening up the possibilities for the discovery of new elements.

Antoine-Laurent Lavoisier's (1743–94) views were a considerable step forward in this direction. Early on, he cast doubt on the idea of four basic elements as propounded by the Greeks:

> On ne manquera pas d'être surpris de ne point trouver dans un traité élémentaire de chimie un chapitre sur les parties constituantes et élémentaires des corps; mais je ferai remarquer ici que cette tendance que nous avons à vouloir que tous les corps de la nature ne soient composés que de trois ou quatre éléments tient à un préjugé qui nous vient originairement des philosophes grecs. L'admission de quatre éléments, qui, par la variété de leurs proportions, composent tous les corps que nous connaissons, est une pure hypothèse, imaginée longtemps avant qu'on eût les premières notions de la physique expérimentale et de la chimie.[14]

He clearly stated his concept of simple bodies: he believed that all substances that scientists had failed to decompose in any way were elements, and he divided all simple substances into four groups. The first group consisted of oxygen, nitrogen, and hydrogen, as well as light and *caloric* (which was, of course, an error). Lavoisier considered these simple substances to be real elements. In the second group Lavoisier included sulfur, phosphorus, coal, a radical of muriatic acid (later called chlorine), a radical of hydrofluoric acid (fluorine), and a radical of boric acid (boron). According to Lavoisier, these all were simple nonmetallic substances capable of being oxidized and of producing acids. The third group contained 17 simple metallic substances "oxydable and acidifiable," ranging from antimony to zinc. And, last, the fourth group included salt-forming compounds (earths), which, however, were known to be complex, including lime (calcium oxide), alumina (aluminum oxide), silica (silicon oxide), and magnesia (magnesium oxide).[15] In 1789, the idea that these substances were oxides of unknown elements was only a conjecture. This classification and the comments about it were still greatly confused and unclear, but, nevertheless, they served as a program for further research into the nature of the elements.

It has been argued that Lavoisier drew no distinction between the concepts of "an element" and "a simple body." In fact, in his preface to the *Traité*, he commented that the elements "were all the substances in which one is capable by any means of reducing . . . by decomposition, and if they may be compounded, we should not suppose them to be so unless this can be proven by experiment and observation." This so-called analytical approach[16] to the elements, one that concentrated on concrete laboratory substances as opposed to metaphysical speculation about the ultimate components of substances, was central to the chemical revolution. The caveat is that this idea is at best a criterion for when a substance should be recognized as an element rather than a definition of "element." Lavoisier's notion of element is thus compositional: he understands the behavior of composite substances to be a direct consequence of the basic substances that they contain. Essentially, Lavoisier assumed that elements survived in their compounds and that they could be recovered from their compounds by the process of decomposition. This is opposed to Aristotle's theory of chemical combination, in which the ultimate components do not persist unchanged in more complex bodies. Actually, Lavoisier did not consciously seek to demolish an abstract concept of elements, but he did seriously compromise the "Aristotelian four" by demonstrating that fire was not a weighable substance but a phenomenon. Seventeenth-century conceptions of the elements—in which they were not viewed as material components of laboratory substances but simply as contributing to the characteristics of composite substances—were much closer to the Aristotelian view.

Paralleling Lavoisier's ideas regarding the nature of elements was his concern with the state of chemical nomenclature at the time. Early on, he criticized the vagueness of chemical expression compared to the precision he found in mathematics and physics. In describing the results of some of his pioneering experiments, particularly with gases, he found it necessary to coin some terms and to find a way of expressing the difference between gases and their aqueous solutions. Meanwhile, Louis-Bernard Guyton de Morveau (1737–1816),[17] probably in early 1787, traveled to Paris to discuss the new antiphlogistic theory with Lavoisier. Guyton de Morveau, under the influence of Torbern Bergman (1735–84), had been ruminating about a new system of chemical nomenclature for many years, so their conversation quickly turned to that topic. Joining them to examine Lavoisier's experiments in support of the new oxygen theory were Antoine-François Fourcroy (1755–1809) and Claude-Louis Berthollet (1748–1822). From discussing the new theory, they went on to discuss the possibility of reforming chemical nomenclature. This historic meeting resulted in the collaborative publication of the *Méthode de Nomenclature chimique*[18] in the summer of that same year.[19] The new nomenclature was itself based on the principle that a body's name ought to correspond to its composition, thus consolidating one more brick in the structure of the chemical revolution.

John Dalton (1766–1844), in 1808, presented a theory of atomism that mirrored Lavoisier's compositional theory: each of Lavoisier's elements possessed a stable, substance-specific kind of atom that survived chemical change.[20] Whereas Lavoisier's very successful definition made no reference to atoms (thus making it acceptable to anti-atomistic chemists such as Wilhelm Ostwald and Marcellin Berthelot), Dalton connected his hypothetical atoms with the elements, proposing that the chemical elements were composed of atoms and that the atoms of a given chemical element were all identical, having the same mass.[21] These ideas were widely accepted and greatly clarified over the course of the 19th century owing to the development of atomic and molecular theory and to the work of Dmitri Ivanovich Mendeleev. The development of the concept of the chemical element at this time was as twisted a pathway as the discoveries of the individual elements, both true and false, and makes for very interesting reading.[22,23]

Amazing new discoveries and developments toward the end of the century heralded great changes in what, by now, was considered the classical concept of the element. When, in 1894, Lord Rayleigh (1842–1919) and William Ramsay (1852–1916) announced the discovery of a monatomic gas with an atomic weight of 39.8, it was thought that this event presaged the toppling of the periodic system. When, in 1896, Henri Becquerel (1852–1908) realized that the penetrating emanation coming from uranium ore was a property of the material itself and not the result of impinging radiation, he had to hypothesize that the uranium was spontaneously undergoing a change. But what was it changing into? How could a hitherto stable, substance-specific simple body be changing right before his eyes? In 1897, J. J. Thomson (1856–1940) discovered corpuscles (later called electrons) being ejected from the atoms of gases in his cathode ray tubes and concluded from further experiments that they were fundamental to all matter, he demonstrated that atoms were not indivisible. In 1898, Marie Skłodowska Curie (1867–1934) and Pierre Curie (1859–1906) discovered two new elements that were far more radioactive (a word coined by Marie) than the parent substances. And, in 1902, Ernest Rutherford (1871–1937) and Frederick Soddy (1877–1956) realized that radioactive substances were actually spontaneously transmuting into new chemical substances.[24, 25] It was clearly time to reexamine the classic idea of the nature of the element and the nature of the atom.

The most immediate problem centered around the idea that atoms were not the immutable building blocks of nature but actually possessed a composite nature consisting of at least electrons and other yet to be determined components. Radioactive transmutations were seen to undermine the very foundations of chemistry. Hence, Mendeleev, and with him many other chemists, was hostile to these new discoveries and to the conclusions drawn from them. Worst of all, these scientists envisioned the actual demise of chemistry by a descent back into alchemy, on the one hand, and a loss of autonomy to physics, on the other.

The year 1913 was crucial. In that year, Henry Moseley (1887–1915) demonstrated that one could identify an element and its numerical place in the periodic table purely by measuring the X-rays it emitted. Frederick Soddy proposed the notion of *isotopes*, wherein two atoms could be chemically identical, with the same atomic number (a consequence of Moseley's Law), but have different atomic weights. These notions were very difficult for chemists to accept: many denied that isotopes behaved in exactly the same way. Gradual acceptance followed, helped along by the discovery of hafnium (the first element to be discovered on the basis of atomic number) and impeded in other ways by the differing mindsets of traditional chemists and those trained to think in terms of physics and physical chemistry. Echoes of these differences resound throughout this book, and they will be easy to identify.

We can think of no better way of expressing the evolution of the concept of element than these words of Tenney L. Davis:[26]

> During the period preceding [Stanislao] Cannizzaro[27] an element was a substance whose combining weight was one particular number or some small multiple of that number. Not long thereafter an element became a substance which had one atomic weight and only one, but that state of affairs did not long prevail. Isotopes were discovered, and an element now is a substance which has an atomic number. The weight-test has disappeared. We resort to X-ray spectra. To the question, What sort of things are the elements? the answer was once given—hard impenetrable atoms which differ in shape, then atoms which differ in weight, compressible atoms, arrangements of electrons and protons, and now apparently arrangements of waves. Yet our abstract notion of element—the natural body or bodies, one or many, of which all things consist, from which they arise, into which they pass away—is the same today as it was in the time of Lavoisier or Boyle, Aristotle or Thales.

IS THERE ANY ORDER TO THE DISCOVERIES OF THE ELEMENTS?

Which element was discovered first?[28] For almost 10 elements, chemistry books report only the words “known from antiquity.” The concept of antiquity is rather loose, and the words mean that these elements were known long before our time. Of course, we do not know who discovered them, although archaeologists can give us more or less reliable information on the time when an element was first used by humans in antiquity (without, of course, being perceived as an element). Elements known in antiquity were iron, carbon, gold, silver, mercury, tin, copper, lead, and sulfur. All these elements differ broadly in their properties. Are they the most abundant elements on earth? As regards abundance, only iron and carbon are among the 10 most abundant elements. Sulfur is also fairly abundant, but the other elements are quite rare on earth. The most abundant elements are oxygen, silicon, and aluminum. Oxygen, the most abundant, was not recognized as a chemical element until the end of the 18th century. Silicon, the main solid component of the earth’s crust, was discovered only in the 19th century, as was aluminum, although clay (alumina) had been used for ages.

The natural abundance of the terrestrial chemical elements is by no means related to the dates of their discoveries. Hence, most of the elements known from antiquity occur in nature as simple substances. Gold, silver, and sulfur occur on earth in the free state (although sulfur is mainly a constituent of minerals); copper and mercury are encountered in the free state much less frequently. But the reason that these elements were among the first to be discovered is that their compounds are easily reduced in the presence of carbon (charcoal). Many scientists believe that our forebears first began to use iron in the free state as meteoritic iron.

The age of discovery of chemical elements began only in the second part of the 18th century.[29] Preceding millennia had seen the discovery of only five new elements: arsenic, antimony, bismuth, phosphorus, and zinc. They were discovered by alchemists who were vainly looking for the Philosopher's Stone but who were also engaged in metallurgy, medicine, and other material occupations that increased the frequency of their chance discoveries. As time moved on, discoveries became increasingly linked to the interpretation of observations and the incorporation of facts and their interpretations into some kind of theoretical framework, along with scientists' greater skill in handling the complex materials given them by Nature.[30]

The discovery of new chemical elements became a routine matter and not a stroke of good luck only after two main conditions had been fulfilled[31]: first, chemistry began to take shape as an independent science, and scientists learned how to determine the composition of minerals. Second, most scientists at last reached a consensus on the concept of chemical element. It was the beginning of the great analytical period in the history of chemistry, in the course of which many of the naturally occurring elements were discovered.

Various analytical methods, constantly being improved, were the key factors that led, step by step, to the discovery of new chemical elements. But chemical analysis by itself was not enough to fill all the boxes in the periodic table. Scientists divined the existence of many new elements not because they discovered them, figuratively speaking, lying on the bottom of a test tube.

Some elements do not form their own minerals but exist only as admixtures to all sorts of minerals containing other elements. They seem to be widely dispersed in the earth's crust and are called *trace elements*, often announcing their presence through a peculiar "visiting card": their spectrum. If a grain of a substance is introduced into the flame of a gas burner and the light is passed through a prism, the refracted light contains a number of differently arranged spectral lines of various colors. By studying the spectra of known elements, scientists came to the conclusion that each element had its own "spectral portrait." Spectral analysis was immediately recognized as a powerful research tool. If the spectrum of a certain substance contained unknown lines, it was logical to assume that this substance contained a new element. However, in such cases, it took courage for scientists to announce the existence of new elements because they did not have a single atom in their hands and did not know the unknown element's properties.

Naturally, the history of the discovery of chemical elements was to a certain extent affected by the abundance factor: those elements less abundant in nature were discovered later than many others. All of them were discovered within about a quarter of a century, from the very end of the 19th century into the beginning of the 20th century. These elements would have remained hidden for an even longer time if analytical techniques had not included the measurement of radioactivity.

Some substances spontaneously emit electromagnetic radiation and matter. At first, it was believed that this phenomenon was a property of certain minerals, but later it was realized that radioactivity was an atomic property, typical of heavy elements like uranium and thorium. When scientists noticed that the radioactive output of a given mineral was greater than its uranium and/or thorium content, they assumed the presence of another element: an unknown element. Polonium and radium were thus discovered. This led to another research method—the radiometric method— that, in the long run, led to the discovery of other naturally radioactive elements.[32]

Radiochemistry gave rise to the development of a new method of analysis, much more sensitive than those previously used. Through its use, by the end of the 1920s, all naturally occurring elements had been discovered. However, this was not the end of the discovery of elements.

In 1934, Irène (1897–1956) and Frédéric Joliot-Curie (1900–58) created the first synthetic isotopes of naturally occurring elements.[33] Thus the expression "discovery of a new element" acquired a new meaning. In 1937, with the aid of nuclear reactions, the chemist Carlo Perrier (1886–1948) and the physicist Emilio Gino Segrè (1905–89) identified the first "artificially synthesized element."[34] From that year on, the discoveries of artificial elements became the purview of physicists and nuclear chemists. This field of research uses complex techniques in which radiometric methods play an important role. All synthesized elements are radioactive, and some of these elements possess an extremely short half-life. Their synthesis and characterization were full of scientific and technical complexities, requiring massive government funding and the collaboration of scientists on an international scale.

This brief summary of the elements that now reside in the periodic table can also apply to those "elements" that have no place there. False discoveries of chemical elements are also the product of the methods used in discovery; their histories are intimately intertwined with the real elements, like the *basso continuo* that accompanies the melody in a baroque concerto. In this book, we bring back to life the history of these false discoveries, for the most part with respect to their chronology.

Although we have drawn on many sources, both primary and secondary, we would like to call attention to two papers, published 76 years apart, that summarized the "lost" elements then known: Charles Baskerville's (1870–1922) 1904 address to the American Association for the Advancement of Science (AAAS)[35] and Vladimir Karpenko's 1980 paper in *Ambix* that examines two outstanding cases of elemental error and presents a comprehensive table, in alphabetical order, of more than 175 erroneous discoveries, complete with references and remarks.[36] A more recent addition to this literature is a paper by J. A. Bustelo, J. Garcia, and P. Román that concentrates on the lost names of the true elements. The paper contains a comprehensive, fully referenced table of these names, proposed and not accepted.[37]

THE DEVELOPMENT OF THE PERIODIC TABLE

"The periodic table…is a map of the way in which electrons arrange themselves in the atoms of a particular element…Its constant use by chemists emphasizes the central role. . .[it]…plays in making sense of what otherwise might be a chaotic jumble of facts about the elements and their many molecular combinations."[38] Today, we can find works that emphasize some of its many other facets—it is no longer a map but a kingdom, with its own limits, rules, and alliances.[39] It has become a cultural icon that can make unlikely connections, such as that between Michelangelo's *Moses* and Cleopatra's ingestion of the ultimate calcium supplement[40]; a mine of colorful anecdotes and odd facts about the discovery of its elements[41]; a system that represents the elements as human figures with periodically changing hairstyles[42]; a thing of beauty and a joy forever[43]; or the source of a life-altering encounter.[44] It is also probably the greatest piece of chemical research accomplished in the process of writing a chemistry textbook!

Although it is not the purpose of this book to exhaustively document the development of the periodic system,[45] especially since this book is devoted to identifying "illegal tenants" who have occupied it from time to time, the topic deserves a few words to set it into context. As with every other scientific breakthrough, the compilation of the periodic table began modestly, with collections of facts about material substances assembled over the course of the centuries. As the concept of "element" became clearer, and as data about the known elements began to accumulate, scientists began to look at the phenomenonological relationships among the elements. But, as van Spronsen points out, "the periodic system was comparatively . . . late in coming . . . due not so much to technical imperfections in atomic weight determinations as to the . . . fact that the theory of chemical bonding, based on Avogadro's hypothesis, was not unanimously accepted."[46]

From his careful work on mineral analysis and composition, in 1817, Johann Wolfgang Döbereiner (1780–1849) identified a triad of elements with similar properties in the mineral celestine. Other triads were added over the following decades, indicating a growing awareness of possible "families" of elements that had in common a simple numerical relationship in their atomic weights. Others who expanded on this idea were Leopold Gmelin (1788–1853) in 1827, Oliver Gibbs (1822–1908) in 1845, Jean-Baptiste Dumas (1800–84) in 1851, and William Odling (1829–1921) in 1857. In 1860, Stanislao Cannizzaro delivered his fiery speech on the importance of atomic weights at the Karlsruhe Conference. In 1862, the French mineralogist and geologist at the Paris École des Mines, Alexandre Emile Beguyer de Chancourtois (1820–86), proposed a natural system of classification embodied in a graphical representation that he dubbed "Vis Tellurique." By plotting atomic weights along a helical curve whose base has a circumference of 16, similar elements tended to arrange themselves in vertical columns.[47] The actual diagram did not appear until the publication of his book a year later.[48] Two years later, the English chemist John Alexander Reina Newlands (1837–98) arranged the known elements in order of increasing atomic weight and noticed that this arrangement allowed one to attribute some order, at least partially, to the properties of the elements (although his idea was scorned when he presented it to the London Chemical Society). In 1869, the Russian chemist Dmitri Ivanovich Mendeleev presented his paper to the Russian Chemical Society "On the Relationship Between the Properties and the Atomic Weight of the Elements,"[49] and he considered this discovery "the direct consequence of all the deductions drawn from the accumulated experiments done towards the end of the decade 1860–1870." In 1870, in Liebig's *Annalen*,[50] Julius Lothar Meyer (1830–95) arrived at the same conclusions, publishing a periodic table of the elements similar to that of Mendeleev. In addition to Meyer's grouping of the elements according to their atomic weight, in many respects resembling our modern periodic table, he also prepared a graph plotting the atomic volumes of the elements against their known atomic weights—a plot that clearly shows the periodic variation of this property.[51] The periodic table was born; it allowed scientists to predict the existence of elements not yet known and also to attribute chemical properties to them.

From these developmental steps, it is quite clear that chemists were beginning to converge on the phenomenological concept of linking the elements by their basic properties. Many historians of science think that Cannizzaro's ideas propounded at Karlsruhe were the catalyst that precipitated the simultaneous discovery of the system a decade later. Both Mendeleev and Meyer had attended the Karlsruhe Conference. Both were influenced by Cannizzaro's paper. Both came up with uncannily similar periodic tables—but Mendeleev was a year earlier than Meyer and less tentative in his conclusions.[52] These ideas had percolated in their minds for a long time. I. S. Dmitriev, director of the Mendeleev Institute at the University of Saint Petersburg, writes: "Mendeleev's discovery of the Periodic Law did not follow a linear pathway, but rather one that was complicated, difficult, winding, one that utilized various criteria over a period of time."[53]

One could certainly say the same for Julius Lothar Meyer. The two chemists arrived at strikingly similar conclusions, and both are accorded equal credit for the discovery. So why is the periodic law associated exclusively with the name of Mendeleev in the popular mind and in much popular literature? Some might say that the discovery of a new element, as almost precisely predicted by the gaps left in Mendeleev's table, seemed to have clinched his claim.

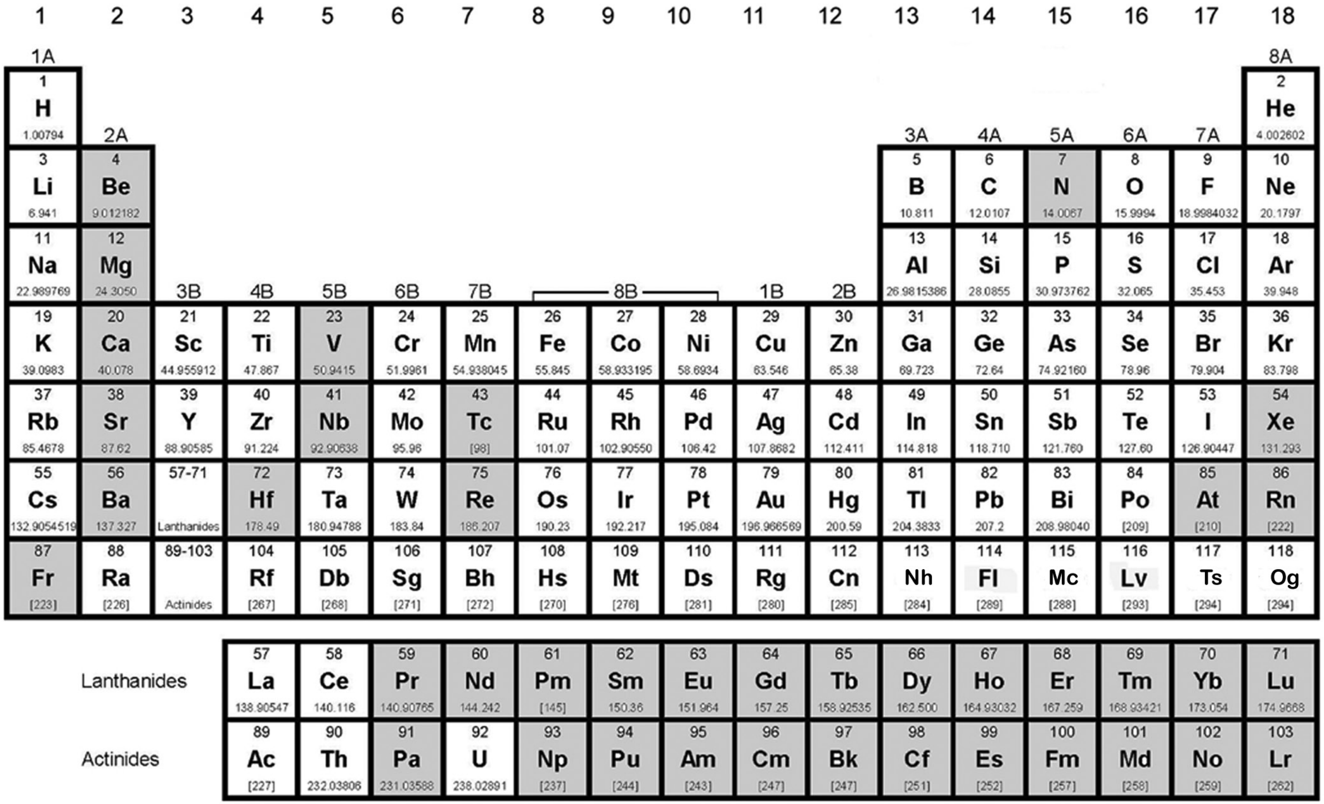
But Mendeleev was not the first to correctly predict the existence of a "missing element." That honor goes to Newlands who, in 1864, correctly predicted an element with an estimated atomic weight of 73 that would lie between silicon and tin. He was very close to the accepted value of 72.64 for germanium, discovered by Clemens Alexander Winkler (1838–1904) in 1886.[54]

Be that as it may, an unfortunate priority dispute between Meyer and Mendeleev ran on throughout the 1870s, and it seems to have revolved around the mistranslation of a single word from Mendeleev's Russian into the German article published in the *Zeitschrift für Chemie: periodicheski* to *stufenweise*. Apparently, the translator did not think it was important to emphasize periodicity and believed that the word for "gradual" or "stepwise" would do quite nicely,[55] whereas Meyer took that word to mean that Mendeleev had not recognized the repeat pattern of properties implicit in the word "periodic." Mendeleev took the initiative in defending "his" system, insisting that it was not enough to simply organize the elements, but also to be able to have an instrument with predictive properties, an idea that he propounded until his death in 1905. With Meyer's death in 1895, there was no one left to take up his cause, so the balance shifted in Mendeleev's favor, helped along by Russia's growing economic importance.[56,57] Thus, Mendeleev is immortalized with a box in his own table, an honor accorded so far to only 14 other human beings.

As technology advanced, many elements were discovered that confirmed Mendeleev's initial predictions. Some bumps along the road were how to accommodate the plethora of rare earth elements and the unexpected discovery of the noble gases and of numerous radioactive species that seemed to be individual new elements until the existence of isotopes came to be understood. Moseley predicted that his X-ray method would "prove a powerful method of chemical analysis.... It may even lead to the discovery of missing elements, as it will be possible to predict the position of their characteristic lines."[58] Following on the results of this landmark paper, chemists realized that only seven of the naturally occurring elements remained to be discovered, thus cutting down drastically the number of reported false discoveries and setting in motion an element hunt full of controversial competing claims that lasted for decades.[59]

Once chemists realized that not only could the periodic system bring order out of chaos and that it had predictive possibilities, but also that it served as a theoretical tool—as a map of the way in which electrons arrange themselves in atoms—it quickly took its rightful place as the "chemist's Bible." It has gone through many revisions since it was first visualized by Mendeleev and Meyer.

The lanthanides, elements 57–71, resemble one another so much that it took the better part of a century and a half to separate and characterize them. Their signature characteristic is that, as the atomic number increases along the series, they are filling in inner f-orbitals with electrons while the chemical properties of the preferred +3 oxidation state remain relatively unchanged. The facts that there is little covalency, that the +3 oxidation



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A																	8A
1 **H** 1.00794	2A											3A	4A	5A	6A	7A	2 **He** 4.002602
3 **Li** 6.941	4 **Be** 9.012182											5 **B** 10.811	6 **C** 12.0107	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984032	10 **Ne** 20.1797
11 **Na** 22.989769	12 **Mg** 24.3050	3B	4B	5B	6B	7B	8B			1B	2B	13 **Al** 26.9815386	14 **Si** 28.0855	15 **P** 30.973762	16 **S** 32.065	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.955912	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.938045	26 **Fe** 55.845	27 **Co** 58.933195	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.64	33 **As** 74.92160	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90585	40 **Zr** 91.224	41 **Nb** 92.90638	42 **Mo** 95.96	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.760	52 **Te** 127.60	53 **I** 126.90447	54 **Xe** 131.293
55 **Cs** 132.9054519	56 **Ba** 137.327	57-71 Lanthanides	72 **Hf** 178.49	73 **Ta** 180.94788	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.084	79 **Au** 196.966569	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.98040	84 **Po** [209]	85 **At** [210]	86 **Rn** [222]
87 **Fr** [223]	88 **Ra** [226]	89-103 Actinides	104 **Rf** [267]	105 **Db** [268]	106 **Sg** [271]	107 **Bh** [272]	108 **Hs** [270]	109 **Mt** [276]	110 **Ds** [281]	111 **Rg** [280]	112 **Cn** [285]	113 **Nh** [284]	114 **Fl** [289]	115 **Mc** [288]	116 **Lv** [293]	117 **Ts** [294]	118 **Og** [294]
	Lanthanides		57 **La** 138.90547	58 **Ce** 140.116	59 **Pr** 140.90765	60 **Nd** 144.242	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.964	64 **Gd** 157.25	65 **Tb** 158.92535	66 **Dy** 162.500	67 **Ho** 164.93032	68 **Er** 167.259	69 **Tm** 168.93421	70 **Yb** 173.054	71 **Lu** 174.9668
	Actinides		89 **Ac** [227]	90 **Th** 232.03806	91 **Pa** 231.03588	92 **U** 238.02891	93 **Np** [237]	94 **Pu** [244]	95 **Am** [243]	96 **Cm** [247]	97 **Bk** [247]	98 **Cf** [251]	99 **Es** [252]	100 **Fm** [257]	101 **Md** [258]	102 **No** [259]	103 **Lr** [262]

FIGURE 0.02. Periodic Table. The grayscale boxes indicate the locations where the false discoveries of elements have been most prevalent. The reason that some elements have been a source of error while others have not is due substantially to two factors, which may be taken individually or combined: the extreme scarcity of some of these elements in nature (such as the elements of atomic numbers 43, 61, 85, 87, and 91) or the similarity of their chemical properties with other nearby elements (rare earths, rhenium, and hafnium). For the transuranium elements, as well as for nitrogen, vanadium, niobium, some noble gases, beryllium, and other alkaline-earth elements, the case is quite different: they are anomalous due to the priority disputes of two or three academic research groups. Finally, other false elements, because of their bizarre nature, have not found a well-defined place in the periodic table of the elements.

state is preferred under normal conditions, and that the atomic radii are not very different all contribute to their chemical similarity. To accommodate the lanthanides would make for a "super long form" table, and so they are often displayed separated from the rest of the table for the sake of convenience.

Alfred Werner (1866–1919) was the first to recognize that yet another intergroup accommodation might be necessary for the heavier elements beyond uranium,[60] a suggestion taken up by Glenn Seaborg (1912–99) in 1944 while his group was struggling with the placement of the transuranium elements in the periodic table. In his own words:

> I began to believe it was correct to propose a second lanthanide-style series of elements... [starting]... with element number 89, actinium, the element directly below lanthanum on the periodic table. Perhaps there was another inner electron shell being filled. This would make the series directly analogous to the lanthanides, which would make sense, but it would require a radical change in the periodic table... [Wendell] Latimer told me that such an outlandish proposal would ruin my scientific reputation. Fortunately, that was no deterrent because at the time I had no scientific reputation to lose.[61]

So today's most common form of the periodic table (Figure 0.02) consists of a main body that includes the s-block, the d-block, and the p-block, along with the lanthanides and actinides that ride along below to better indicate the difference in their inner-electron arrangement.

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The Lost Elements

PART I

Before 1789

Early Errors and Early Elements

Sola manent interceptis vestigia muris,
ruderibus latis tecta sepulta iacent.
Non indignemur mortalia corpora solvi:
cernimus exemplis oppida posse mori.
[Only traces are left in ruins and remains of walls,
Roofs lie buried in vast ruins.
Let us not be resentful that mortal bodies disintegrate:
Behold: Even cities can die.]
—Claudius Rutilius Namatianus

PROLOGUE TO PART I

In Part I, we examine, analyze, and discuss the errors in discovery that occurred some years prior to Lavoisier's masterful contribution that moved the chemical sciences toward a new understanding of the concept of a chemical element. Therefore, these errors cannot be judged by the same standards as those treated in other sections of the book. These cases are confined to a very short period of time leading up to 1789, the date we arbitrarily select as the dividing line between protochemistry and chemistry. Prior to 1750, there is no evidence of a false discovery among solids, liquids, or gases.

Due to both the brief period of time under investigation and the limited number of chemists and technologists working in the Western world in the second half of the 18th century, fewer than a dozen erroneous findings are discussed in this section. Some of the substances are called "earths" according to the prevailing custom of naming the oxides of an element. In other cases, element names are given in Latin, the official language of culture and science for more than a thousand years, and in yet others, names were given in local languages.

The cases examined in Part I deal exclusively with solids, for three major reasons:

- Very few elements are liquid at room temperature. Mercury was known since antiquity; the likelihood of coming across another, such as gallium or iodine, in that period was very poor;
- Regarding the gaseous elements, pneumatic chemistry had reached a sufficient degree of experimental sophistication, and gas analysis was reasonably reliable. However, the technology for liquefying and distilling the constituents of air (noble gases) was well beyond the reach of 18th-century chemists;
- There was an increased interest in the study of metals and minerals in Europe during this period, due in large part to the vital link between the prosperity of a nation and the productivity of its mines. Consequently, the degree of development of analytical chemistry and metallurgy was in direct proportion to the scientific exploitation of mining.

I.1

THE BEGINNING OF A LONG SERIES OF SCIENTIFIC BLUNDERS

I.1.1. TERRA NOBILIS

The enthusiasm that often characterizes researchers can at times distort certain preconceived convictions and deceive the scientist into believing that a controlled experiment has produced the correct result when, in fact, it is erroneous due to insufficient or incorrect data. This is the case for the discovery of a mysterious *terra nobilis* made by the chemist Torbern Olof Bergman.

Bergman was born on March 20, 1735, in Katrineberg,[1] Sweden. He was a chemist and mineralogist who became famous in 1775 for printing the most extensive tables of chemical affinity ever published at that time, and he was the first chemist to use letters of the alphabet as a notation system for chemical species. He took his doctorate at the University of Uppsala in 1758. After initially holding the professorship of physics and mathematics, he later took the chair in chemistry, which he retained for the rest of his life. Bergman made significant contributions to progress in quantitative analysis and metallurgy, and he developed a classification scheme of minerals based on their chemical characteristics.

In 1777, Bergman confidently announced[2] the result of an extremely expensive investigation. He studied the behavior of diamond with a blowpipe, and, aside from the presence of silicon, he seemed to have generated an unknown compound. He extracted the oxide of a metal from the diamonds, which, according to the custom of the time, he called *terra nobilis*. His discovery was quickly forgotten, not least because his life soon took a tragic turn.

After marrying Margareta Catharina Trast in 1771, he enthusiastically continued his activities as a synthetic and analytical chemist,[3] but on July 8, 1784, at the age of only 49, he died in Medevi, Sweden. It is believed that he fell victim to poisoning from the chemical substances he used in his research. At the time of his death, he had been a member of the Royal Society of London and the Swedish Royal Academy for many years, and he was certainly one of the most famous chemists of his time. In fact, his funeral eulogy was conducted by Marie Jean Antoine Nicolas de Caritat, Marquis de Condorcet (1743–94) and the anatomist Felix Vicq-d'Azyr (1748–94).

I.1.2. SIDERUM AND HYDROSIDERUM

At the end of the 18th century, there existed a particular type of iron called *fer cassant a froid* due to its tendency to crumble when cold; when hot, however, it was malleable like a common metal. In Uppsala during those years, Torbern Olof Bergman was investigating the origin of this strange property of iron, while on the opposite shore of the Baltic sea at Szczecin (Stettin), Poland, Johann Karl Friedrich Meyer (1733–1811) was also studying the same problem. Between 1777 and 1778, both scientists, working independently, discovered that by the action of sulfuric acid on *fer cassant a froid*, a white powder was formed. By a process of reduction (the details of which are not known), the white powder was converted into a fragile gray substance with an appearance similar to that of a metal but not very soluble in acids. The specific gravity of the substance was 6.700. It did not melt easily and, once combined with iron, it regenerated the substance *fer cassant a froid*. Both proposed that the unknown substance mixed with iron could be a new element. Bergman suggested that it be called *siderum,* whereas Meyer proposed the name *hydrosiderum*[4] or *wassereisen*. Martin Heinrich Klaproth (1743–1817), working in Berlin, immediately connected these observations with his own experiments in the field. He had noted that when iron was combined with phosphorus, a white product was formed with an appearance similar to that of the so-called *fer cassant a froid*. His initial suspicion that *siderum* and *hydrosiderum* were in fact an alloy of iron and phosphorus was confirmed by subsequent chemical analysis. To resolve the mystery, Klaproth heated phosphoric acid with iron and carbon and obtained a white powder very similar to the *hydrosiderum* of Meyer and the *siderum* of Bergman.[5] Meyer, when Klaproth informed him of the outcome of his experiments, replied that he, too, after a long analysis, had found that *hydrosiderum* contained phosphoric acid.[6] Shortly afterward, the chemist Carl Wilhelm Scheele (1742–86) became interested in the problem of the composition of *fer cassant a froid*. He approached the problem by decomposing the substance, thus identifying phosphoric acid and iron.[7] Although it contained the same elements as *hydrosiderum* (iron and phosphorus), in *siderum,* phosphorus was not present as phosphoric acid but as elemental phosphorus or as iron phosphide.

Finally, the Swedish chemist Sven Rinman (1720–92) managed to demonstrate that the fragility and other poor qualities (from a metallurgical point of view) of *fer cassant a froid* could be removed by heating the alloy in a reducing atmosphere.[8]

Johann Karl Friedrich Meyer worked as a pharmacist for many years in his native town and, in 1784, became member of the Academy of Sciences in Berlin. He died at Szczecin on February 20, 1811, at the age of 78.

I.1.3. SYDNEIUM OR AUSTRALIUM

In 1779, during a session of the House of Commons, the naturalist Joseph Banks (1743–1820) expressed the urgent need to establish a new crown colony in Australia. The government demonstrated an interest in creating new penal colonies, although to observers of the time it seemed almost insanely expensive. However, due to the loss of the North American colonies, there was terrible overcrowding in the English prisons and a solution needed to be found quickly. The first colonists and prisoners set sail a few years later and, in January 1788, the first settlement was established in Sydney Bay, in a region now called New South Wales. Two years later, an article was published in the Royal Society's *Philosophical Transactions*, of which Banks was president, with the title "On the Analysis of a Mineral Substance from New South Wales."[9] The author was the well-known producer of and expert on ceramics, Josiah Wedgwood (1730–95), who from 1783 had been an elected member of the Royal Society for his studies on pyrometry. Josiah Wedgwood was born at Burslem on July 12, 1730. He had an excellent sense of observation, but only limited schooling. His contact with chemistry and mineralogy came through meetings with members of the Lunar Society of Birmingham—the source of the scientific notions that were to lead him to become a master producer of ceramics and porcelain,[10] renowned throughout the world.

This informal but notable Society, so-called because its members used to meet every month on the Monday closest to the full moon, counted among its members many distinguished scientists, including James Keir (1735–80), Joseph Priestley (1733–1804), James Watt (1736–1819), William Withering (1741–99), and Erasmus Darwin (1731–1802), grandfather of the more famous Charles Robert Darwin.

The cover letter of Wedgwood's article to the *Philosophical Transactions* of the Royal Society, addressed to Banks, reveals the reasons for Wedgwood's commercial interest in certain new minerals originating in Australia: "I have the pleasure of acquainting you that the clay from Sydney Cove, which you did the honour of submitting to my examination, is an excellent material for pottery, and may certainly be made the basis of a valuable manufacture for our infant colony there." He then elucidated arguments of a more chemical nature: "The other mineral. . . seems to contain one substance hitherto unknown." Wedgwood reported the analysis that he and his assistant (Mr. Chisholm) had carried out on that material. The mineral was described as mixture of fine white sand, particles of mica, and a soft white soil. The analysis proved to be quite difficult due to the modest instrumentation available and because the material was soluble only in hot hydrochloric acid and precipitated as a white powder upon addition of small amounts of alkali. They succeeded in melting the white powder (perhaps an oxide) at high temperatures but could not obtain the free metal on reduction with charcoal. Wedgwood concluded that the substance was not a combination of an unknown earth with an "acid radical." Furthermore, he was unable to say whether the new substance was "an earth" (metallic oxide) or metallic, although his experience suggested the first hypothesis. The German anthropologist Johann Friedrich Blumenbach (1752–1840), at the University of Göttingen, confirmed some of Wedgwood's observations and thus enabled the presumed discovery to become known on the continent. Although Wedgwood had not given a name to the new earth, in the textbooks of the time the names *sydneia* (element = *sydneium*), *australa* (element = *australium*), and *terra australis* were attributed to it. In French texts, for a short period, it was known as *terre de sidnei*, whereas for the English it was *austral sand*. In Berlin, in 1797, the chemist Martin Klaproth undertook a careful and detailed investigation of the so-called *sydneia* or *austral sand*, finding only alumina, silica, and traces of iron. William Nicholson (1753–1815), writer, editor, and officer of the East India Company, opposed Klaproth's findings. He asserted that because Klaproth had not analyzed the same material as Wedgwood there were no grounds for rejecting Wedgwood's discovery. Because it was well known that Nicholson had traveled around the world on behalf of the Wedgwood Company, his statement was confidently regarded as correct. The controversy was finally laid to rest the following year when Charles Hatchett (1765–1847) stated, contrary to Nicholson, that he had proof that the samples analyzed by Wedgwood and Klaproth had the same provenance. In fact, both derived from the original sample donated by the president of the Royal Society, Joseph Banks, to Wedgwood.

Shortly before his death, the Viennese chemist Karl Haidinger (1756–97) gave to Klaproth the sample of Australian sand that he himself had obtained from Hatchett. Hatchett had already analyzed a small amount of the mineral and found the same substances subsequently reported by Klaproth.[11] The two analyses were in accord, except that Hatchett also found traces of graphite.

Thus, the names *sydneia* and *austral sand* disappeared from the list of new substances. Today, Wedgwood's results can be explained by the simple hypothesis, already aired by Hatchett, that he had used poor-quality reagents that led his analysis into error. Wedgwood did not suffer the shame of a public retraction because he died a few years before his discovery was rejected.

Today, the name of Wedgwood is still well known, although it is no longer linked to chemistry but rather to the ceramic industry. He created a pottery industry indebted to his scientific experiments and was one of the greatest pioneering industrialists of his age. He experimented with several clay mixtures that were to contribute considerably to his success as a pottery producer (producing such colors as antique red, cane, drab, chocolate, and olive). Wedgwood died at the age of 64 on January 3, 1795.

Wedgwood's designs are still used today by the Wedgwood company. His original pieces are highly regarded antiques, and Wedgwood porcelain and ceramic products are used around the world, making the company one of the most famous producers of porcelain.

I.1.4. THE ELEMENT THAT BREATHES

The German physician Samuel Christian Friedrich Hahnemann (1755–1843), born in Meissen on April 10 or 11, 1755, is credited as the founder of the alternative form of medicine called homeopathy.[12] His publications, however, also covered topics in chemistry.[13] He studied medicine at the University of Leipzig and subsequently at Erlangen, where he graduated in 1779. During this period, he became a Freemason.[14] In 1782, he married Johanna Kuchler, with whom he had 11 children. The family moved continually from one town to another within Prussia. Hahnemann did not practice medicine, but followed with interest new discoveries in chemistry and dedicated his time to the study and translation of medical texts. In 1801, while in Hamburg, Hahnemann announced that he had discovered a new alkali metal[15] that displayed properties very different from those of the other first-group elements known at that time. The most unusual of these properties concerned the effect of temperature: upon heating the material, its volume increased by a factor of up to 20. The name that he chose for the new substance reflected this peculiar property, which was similar to "inorganic respiration"—*pneum-alkali*, an alkaline element possessing a lung. In the solid state, the element *pneum-alkali* was characterized by hexahedral crystals, lack of ability to absorb humidity from the air or to display efflorescence, and solubility in hot water. Hahnemann did not reveal how he had discovered the new metal, but he did present a long and detailed analysis of its most common derivatives. The sulfate of *pneum-alkali* was not soluble in "ardent spirits," but dissolved in nitric, phosphoric, and acetic acids. The salt derivatives of *pneum-alkali* were soluble in water, whereas the chlorides had a "feathered" appearance. It also displayed the characteristic strongly reducing property of all alkaline elements. On combining the elemental form of *pneum-alkali* with transition metal salts, they were reduced to the metallic state. The new metal seemed to possess a wide range of properties, such as the saponification of vegetable oils and the capacity to react with both the oxychloride and nitrate of mercury. It was able to change the color of certain natural pigment-based dyes from blue to green. These wide-ranging properties convinced Hahnemann to commercialize his discovery by opening a shop in Leipzig where he sold vials containing an ounce (0.03 kg) of the metal for the price of one gold coin (issued by the King of Prussia, Friedrich II). The news of

Samuel Hahnemann's discovery did not pass unnoticed. The fact that he was an atypical physician and a chemist hostile to established ideas led many in the scientific community to press for an investigation. The discovery of the new alkaline element, combined with Hahnemann's desire to gain personal benefit from it, provided an ideal occasion for this, offering a pretext for the major chemists of the time to discredit him.[16]

As soon as the discovery of *pneum-alkali* was announced, the Society of the Friends of the Natural Sciences of Berlin, which counted among its members many of the principal chemists of the time, obtained a sealed, intact vial containing an ounce (0.03 kg) of *pneum-alkali*. The outcome of the analysis carried out by three illustrious chemists, Martin Klaproth, Dietrich Ludwig Gustav Karsten (1768–1810), and Sigismund Friedrich Hermbstaedt (1760–1833), left no doubt: *pneum-alkali* was not a new metal but simply a borate. In their communication, the three chemists invited Hahnemann to publish a full retraction and offer compensation for the fraudulent sale of an ounce (0.03 kg) of *pneum-alkali* for a gold coin when the same quantity of borate could be bought in any pharmacy for a few pennies. A violent attack on Hahnemann's work was also reported by Johann Bartholomäeus Trommsdorff (1770–1837), professor at Erfurt (Germany). He found that the sealed vials sold for an exorbitant price contained only borate and natron.[17] Trommsdorff attacked Hahnemann thus: "A great deal of impudence is required to pull the leg of the worthy German chemical fraternity, and to defraud them of their money." Hahnemann replied to the accusations by publishing a letter proclaiming his innocent intent: "I am incapable of wilfully deceiving: I may however, like other men, be unintentionally mistaken. I am in the same boat with Klaproth and his diamond spar."[18] Hahnemann continued providing a detailed explanation of the causes of his errors. Professor Alexander Nicolaus Scherer (1771–1824), who had published the first results of the discovery of *pneum-alkali*, remained loyal to Hahnemann, counterattacking Trommsdorff and reminding him of the many mistakes that he had also committed during his career as professor of chemistry at Erfurt. However, it was now too late for such exchanges, and Hahnemann was banned from the scientific community. His exclusion was not so much the consequence of his mistake, but rather because he was considered different, an exponent of "heretical" ideas within the scientific establishment.

I.1.5. THE BIRTH OF HOMEOPATHY

After the controversy concerning the discovery of *pneum-alkali*, Hahnemann directed his interests toward the medical field. He believed that medicine at that time caused more harm than good, typified by common practices such as bloodletting (which remained widely used until the end of the 19th century) and purgative and emetic practices that were supposed to remove illness from the patient and restore the correct balance of the four "humors."[19] He refused to accept the concept that to cure an illness, the causative matter should be removed from the body. He advocated instead that to restore harmony and equilibrium within the body the patient needed fresh air, good food, and exercise. Hahnemann's proposal was certainly more humane and less dangerous than the most widely used medical practices of the time, and Hahnemann formulated the basis of homeotherapy while translating the volume *Materia Medica Pura* (Pure Medical Matter), by the Scottish physician William Cullen (1710–90). At that time, malaria was treated by use of an extract from the bark of cinchona: Cullen believed that the effectiveness of quinine was due to its "tonic effect on the stomach." Hahnemann dismissed this idea because many other substances more astringent than quinine did not relieve the fever; thus, some other property had to be the origin of quinine's therapeutic effects. Hahnemann decided to experiment with quinine on himself and, after taking it for several days, he believed that he had developed the symptoms of malaria. He hypothesized that a series of symptoms could be cured by the substance that in a healthy person produced the same effects. In 1806, Hahnemann published his first important work *The Medicine of Experience*, which already contained the fundamental principles of homeopathy (from the Greek *omeos*, "similar" and *pathos*, "illness"), but the basic aspects of his methods had been published 10 years earlier:[20]

- *Experimenta in homine sano*: the effect of medicines can only be discovered by experiments on healthy people because in ill people the symptoms of the illness are obscured by those caused by the medicine.
- *Similia similibus curentur*: the medicine must be chosen on the basis of the similarity between its effects and the symptoms of the patient, without reference to the presumed illness that caused the symptoms.
- *Doses minimae*: medicines must be administered in small doses.
- *Unitas remedii*: the treatment should be repeated only if the symptoms return.

In 1810, Hahnemann published the first edition of his principal theoretical work, *The Organon of Rational Healing*, later retitled as *The Organon of the Art of Healing*. This edition was followed by five others, the last published posthumously in 1921.

Upon his return to Leipzig for the fourth time, Hahnemann began lecturing on homeopathy at the university, where he encountered strong opposition from other physicians and pharmacists. During this period, he carried out many experiments with a small group of students to test the effects of numerous substances. The results were published in a text of six volumes called *Materia Medica Pura* (Pure Medical Matter). It should be recalled that the importance of self-suggestion (the *placebo effect*) was not well understood at that time, and Hahnemann's experiments took no account of it; his students knew which substances they were taking and what effects were expected.

In 1820, Prince Karl Philipp zu Schwarzenberg (1771–1820), an Austrian field marshal and hero of the battle of Leipzig, went to Hahnemann for a cure for his disabling stroke. Unfortunately, the prince died, his death was blamed on Hahnemann's incompetence, and the physicians and pharmacists of Leipzig managed to obtain an order to impede Hahnemann from distributing his medicine. Unable to practice his profession, Hahnemann left Leipzig. In 1821, he moved to Kothen, where he subjected his theory to a profound re-evaluation in order to reply to the many criticisms leveled against it. His growing support for the doctrine of vitalism is evident from this study. To avoid the collateral effects of his medicines, Hahnemann continually reduced the doses, reaching extremely low levels. To combat the objection that such low doses could not be effective, Hahnemann replied that the efficacy of his remedies was considerably increased by a process called "dynamization," which consisted of repeatedly shaking the product up to 100 times.

At the same time, he developed his theory on chronic disturbances. In 1827, he confided to his two most trusted students that he had discovered the causes of all chronic diseases and how to cure them, which he published in the treatise "Chronic Illnesses."[21] In Hahnemann's view, all chronic illnesses, except those caused by orthodox medicine

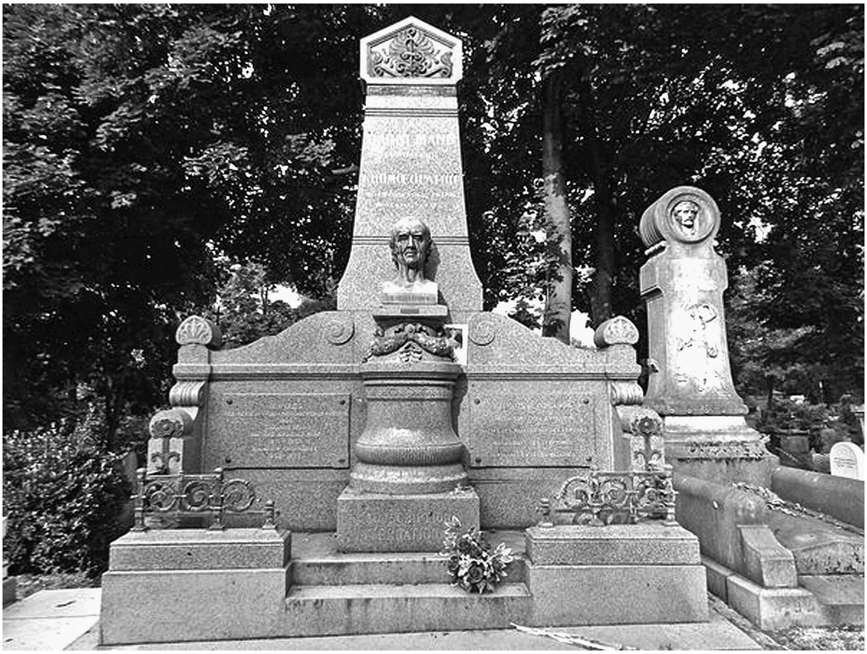

FIGURE I.01. Monument to Christian Friedrich Samuel Hahnemann (1755–1843). Founder of homeopathy and discoverer of the element that breathed, hence the name *pneum-alkali*. Hahnemann is buried in Paris's Père Lachaise Cemetery, Division 19. The plaque on the left is a partial catalog of his works on homeopathy; on the right are quotations from his major work of 1810, *The Organon of Medicine*. Photograph by Mary Virginia Orna.

or a bad lifestyle, were caused by four kinds of "miasma" or poisonous vapors: syphilis, psychosis, tuberculosis, and psoriasis. Contradicting his own principles, Hahnemann experimented with his products on chronic patients, leading him to attribute to his medicines a series of symptoms that were in fact caused by the illnesses themselves. Although Hahnemann's first criticisms of orthodox medicine were empirically based, this evolution of the theory was based primarily on the doctrine of "vitalism" and not on a correct application of scientific method. For this reason, he was increasingly criticized, even by some of his followers. The first controversies among homeopaths were fostered by Hahnemann himself, who attacked without reserve as "traitors" and "apostates" those who brought about even small changes to his "medical theory."

After the death of his wife in 1835, at the age of 80, he married Marie Melanie d'Hervilly (1800–78), who was little more than 30 years old.[22] Shortly afterward, they moved to Paris, where Hahnemann died in 1843. He was buried in the cemetery of Père Lachaise (Figure I.01). Hahnemann's controversial ideas continue to find followers even today, despite the warnings of the modern medical profession.

Notes

1. Apparently a hamlet presently reduced to a single mailbox in Låstads parish, according to element sleuths James and Jenny Marshall. Private Communication, January 21, 2013.
2. Hibben, J. G. *Inductive Logic*; Read Books: Alcester, UK, 2007, p. 272.

3. Among Bergman's many discoveries, one must certainly recall fixed air (CO_2), oxalic acid, and hepatic gas (H_2S).
4. Meyer, J. K. F. *Schriften der Gesellsch. naturf. Freunde* **1780**, *2*, 334; Meyer, J. K. F. *Schriften der Gesellsch. naturf. Freunde* **1780**, *2*; 380; Meyer, J. K. F. *Beschaft. der Gesellsch. naturf. Freunde* **1782**, *3,* 74.
5. Klaproth, M. H. *Crell's Annalen* **1784**, *1*, 390.
6. Meyer, J. K. F. *Crell's Annalen* **1784**, *1*, 195.
7. Scheele, C. W. *Crell's Annals*, English Translation, **1784**, *1*, 112.
8. Rinman, S. *Ann. de Chimie* **1829**, *42*, 831.
9. Wedgwood, J. *Phil. Trans.* **1790**, *80*, 306.
10. Although it digresses from the principal theme, it is worth spending a few words on Wedgwood. Wedgwood's fame was not due to his work as a chemist or mineralogist, but for his ceramics and porcelain inspired, in form and decoration, by classical antiquities. After a short partnership with John Harrison at Stoke-on-Trent in Staffordshire, in 1759, he founded a business with Thomas Whieldon. In 1765, Wedgwood began the production of a cream-colored durable ceramic known as creamware. This ceramic was much appreciated by Queen Charlotte (1744–1818); after receiving her patronage the name was changed to Queen's Ware. The publicity that followed led to its becoming the preferred choice for high society in England and overseas. Many manufacturers suffered from the appearance on the market of this new competitor, even those of international standing such as Sèvres and Meissen. Those that survived began to imitate the cream-colored Wedgwood ceramic, which on the continent was called Fine Faienceware or English Faience. From 1768 on, production was directed toward hard porcelain without enamel, decorated with subjects of the classical world. The most important being black basalts, which imitated Greek vases and jaspers, which were very fine-grained porcelain glasses obtained by the effect of very high temperatures on clay mixtures containing barium sulfate. The Jasperwares, porcelain products prepared from jaspers, were imitated by Sèvres and Meissen, where it was called Wedgwoodwork. In 1774, the Empress of Russia, Catherine the Great (1729–96), a noted collector of porcelain and ceramics, commissioned a service of 952 pieces from Wedgwood. In the same year, an opaque glass ceramic was invented that was to become important for the creation of engravings, cameos, and medallions. Many of the products from the Wedgwood factory were reminiscent of the ornaments originating from the most recent archaeological sites, although the colors of the decorative elements were modified to render them colder and more delicate, according to the tastes of the time.
11. Hatchett, C. *Phil. Trans.* **1798**, *88*, 110.
12. von Lippmann, E. O. *Chemiker Zeitung* **1926**, *50*(4), 25.
13. Kleiner, I. S. *Sci. Mon.* **1938**, *46*, 450.
14. Cook, T. M. *Samuel Hahnemann: The Founder of Homeopathic Medicine*; Thorsons: Wellingborough, U.K., 1981.
15. Anon., *A Journal of Natural Philosophy, Chemistry and the Arts*, **1801**, *4*, 523; Hahnemann, C. F. S. *Scherer's Journal of Chemistry* **1801**, *5*, 665.
16. Haehl, R. *Samuel Hahnemann: His Life and Work*; Jain B. Publisher: New Delhi, India, 1995.
17. The term "natron" was used to indicate hydrated sodium carbonate, chemical formula $Na_2CO_3{\cdot}10H_2O$. Its name derived from the Latin word for sodium, *natrium*. In Egypt, where there were extensive deposits, it was used in mummification due to its property as a drying agent.
18. Professor Klaproth, who at the time of the accusations against Hahnemann was the most prominent living German chemist, just a few years earlier in 1788 had also made a blunder, mistakenly identifying a substance as being newly discovered and calling it *diamanthspatherde* or *terra adamantina* (adamantine earth) (Klaproth, M. *Beschaft. Ges. Nat. Fr.* Berlin, **1788**, *8*, 4; *Crell's Chem. Annalen* **1789**, 5). He indicated *terra adamantina* as a new substance resistant to acids. *Diamanthspatherde* could be melted by addition of alkalis, and its properties were

similar to those of silicon. Today, we know that *diamanthspatherde* is constituted by one-third corundum, Al_2O_3, and two-thirds aluminite, $Al_2(SO_4)(OH)_4$ 7 H_2O.

19. The four humors, phlegm, black bile, yellow bile, and blood were part of the cosmology passed down from the ancient Greek philosophers and were allied with the cosmology of the four Aristotelian elements, earth, air, fire, and water. See https://www.nlm.nih.gov/exhibition/shakespeare/fourhumors.html (accessed April 9, 2014).
20. Pingel, S. *Der Hautarzt: Zeitschrift fuer Dermatologie, Venerologie, und verwandte Gebiete* **1992**, *43*(8), 475.
21. Bradford, T. L. *The Life and Letters of Dr. Samuel Hahnemann*; Boericke & Tafel: Philadelphia, PA, 1895.
22. Marie Melanie d'Hervilly belonged to one of the oldest noble families of Paris. A successful painter and poet, her illness due to cholera directed her attention to homeopathy and the treatment by Dr. Frederick Foster Hervey Quin (1799–1878) during the 1832 cholera epidemic in Paris. Quin was a prominent English homeopath who had been a student of Hahnemann. She obtained a translation of the 1829 fourth edition of the *Organon*, which led her to travel to Kothen to be treated by its author, Dr. Hahnemann. She arrived on October 7, 1834, and began her cure with Hahnemann, who not only treated her illness but also secretly courted and then married her on January 18, 1835.

1.2

THE ELEMENTS HIDDEN BY ALTERNATIVE NAMES

Some well-known elements could have had quite different names. The discoverers of these elements, after "baptizing" them one way later renamed them, more or less voluntarily, with names that are still in use today. This is the case for *ceresium*, a metal now known as palladium, and for *ochroite,* which, if it had been accepted, would have replaced the name cerium.

Tellurium might also have had another name, *metallum problematicum*, although the practicality of such a name in common usage is doubtful. The discovery and naming of *erythronium* or *panchromium* presents a complex issue because, although the substance—later known as vanadium—was indeed an element, it was not recognized as such at the time of its discovery.

1.2.1. METALLUM PROBLEMATICUM OR TELLURIUM

The discovery of tellurium was the unexpected result of an analysis by Hungarian chemist Leopold Anton Ruprecht (1748–1814). In 1782, his interest was focused on the analysis of a rock (nagyágite[23]) coming from Transylvania. This substance was a true chemical puzzle and was suspected of containing a large amount of gold. Ruprecht did not accept this idea, which a quick analysis might suggest, but claimed to have found antimony instead.

Ferenc Müller von Reichenstein (1740–1825), one of Ruprecht's teachers and an inspector of mines in Transylvania, analyzed the rock vein where nagyágite had been obtained and demonstrated the presence of bismuth. Ruprecht replied confidently that the constituent in question could not be bismuth. Müller von Reichenstein admitted his mistake but remained convinced that the mineral contained an unknown metal. Shortly afterward, Ruprecht also admitted that he was no longer convinced of the presence of antimony.

After this exchange of opinions, in 1783, Müller von Reichenstein published an article on the composition of nagyágite that reported the presence of an unknown semimetal that he called *metallum problematicum*.[24] He listed the characteristic reactions of this element and concluded by declaring that he would send a sample of the new substance to Torbern Bergman in Sweden, requesting that he should confirm the new discovery (Bergman was considered to be the greatest living mineral chemist). Bergman began his analyses but shortly afterward asked Müller von Reichenstein to send by ship a more abundant amount of the sample. It is very likely that Bergman never received the new samples since he died 2 months after sending the request.

At this point, when all seemed to be leading to inevitable success, Müller von Reichenstein interrupted his research on *metallum problematicum*. Ten years later, in 1793, when the whole episode was nearly forgotten, the chemist Martin Heinrich Klaproth asked

Müller von Reichenstein for samples of the presumed metal so that he could carry out a detailed analysis in the hope of confirming the discovery. The outcome of the analysis supported Müller von Reichenstein's stance: the sample contained an unknown element. Unfortunately, Müller von Reichenstein was unable to provide the new substance with a name to his liking, thus allowing Klaproth to take advantage of the situation—within the scientific community, the accepted name of the new substance became tellurium.

I.2.2. OCHROITE OR CERIUM

Ten years later, Martin Heinrich Klaproth[25] was again in the limelight for the discovery of a new metal. In 1803, Klaproth, working in Germany at the same time as the Swedish chemists Jöns Jacob Berzelius (1779–1848) and Wilhelm Hisinger (1766–1852), found a new substance that he called cerium. The metal was extracted in the form of an oxide from the minerals cerite and ochroite. The properties of cerium oxide were reminiscent of those of the recently discovered yttrium oxide. In fact, they seemed identical except that yttrium was insoluble in a solution of ammonium carbonate, and yttrium oxide acquired a brown color upon heating.

As in the case of the first lanthanide, also discovered simultaneously by Klaproth and Berzelius, each decided to propose a name of his own choice for the new metal. The name "cerium," still in use today, was given by Berzelius, who had been inspired by the name of the asteroid Ceres, discovered 2 years previously (1801). Klaproth instead suggested the name "ochroite" due to the yellow-brown color of the metal oxide (in English, *ochre* and in Greek, ώχρός).

The attribution of the name was complicated by inappropriate behavior on both sides. Berzelius and Hisinger sent the results of their experiments to Adolph Ferdinand Gehlen (1775–1815), editor of the German *Neues Allgemeines Journal der Chemie*. To support their claim, they printed, at their own expense, a small pamphlet[26]; limited to only 50 copies, today, it is a true collectors' item. Independently, Klaproth, who had analyzed the same tungsten-rich mineral from Bastnäs in Sweden, presented his results, using the name "ochroite," to Gehlen's *Journal*. His article appeared in an issue preceding that of his Swedish colleagues, Hisinger and Berzelius.

It is not clear in what order Gehlen received the two manuscripts, but in a letter sent to Hisinger in May 1804, Gehlen credited Hisinger and Berzelius as the discovers of the metal and gave them the honor of naming it. Klaproth accepted the decision against him with good spirit, suggesting only a slight modification of the name to *cererium*, adding a syllable to emphasize that the etymology of the new metal's name derived from the Roman divinity Ceres and not from the Greek κηρα, which means wax.[27]

As in the case of the name *ochroite*, the modification of the name cerium into *cererium* was not accepted. This double failure undoubtedly represented a difficult (albeit brief) period for Klaproth. His fame as a chemist was growing by leaps and bounds, and not only in Germany. A few months later, he learned that J. F. John had decided to dedicate a new element to him, calling it *klaprothium*[28] (during the year following Klaproth's death, a similar suggestion was made). Martin Heinrich Klaproth died in Berlin on January 1, 1817, at the age of 73.

I.2.3. CERESIUM OR PALLADIUM

The bizarre story of the discovery of palladium involves Andreas (or Jedrzej) Śniadecki (1768–1838), known as a talented Polish scientist and an advocate of Lavoisier's innovative ideas. He became professor of chemistry and pharmacy in the city of Wilnius, at that time part of the Russian empire. This gave him full opportunity to begin the characterization of minerals from rich platiniferous deposits in the Urals. In fact, while analyzing platiniferous material, Śniadecki suspected that he had identified a new element that he called *vestium* (or *vestalium*), fascinated as he was by the recent discovery of the asteroid Vesta.[29,30] The Paris Academy of Sciences, in conjunction with the Academy of Saint Petersburg, never confirmed Śniadecki's results, although the Russian academy, after an initial decree to suppress publication, allowed publication of the presumed discovery. In the eyes of many academics, however, Śniadecki had simply rediscovered palladium. James and Virginia Marshall present a cogent argument for this conclusion in their 2011 paper.[31]

The actual discovery of palladium was made by William Hyde Wollaston (1766–1828) who, 5 years earlier, in 1803, had isolated the noble metal at the same time as rhodium. Wollaston found it in a platiniferous mineral from South America. He dissolved the rock in *aqua regia,* subsequently neutralized the solution with sodium hydroxide, and treated it with ammonium chloride to precipitate the platinum in the form of ammonium chloroplatinate. Upon subsequent addition of mercury cyanide to the remaining liquid, palladium cyanide formed that, when heated in a reducing atmosphere, produced metallic palladium. Initially (i.e., in 1802), he considered calling this metal *ceresium*.[32] However, 2 years later, perhaps because Hisinger and Berzelius had proposed a similar name, "cerium," for their element in 1803 (before Wollaston published his own findings), he decided to use the name of one of the first observed planetoids: palladium, in honor of the asteroid Pallas,[33] discovered 2 years previously.

Exactly 100 years after the death of Jedrzej Śniadecki, in 1938, an article was published in Poland with the intention of restoring credibility to the discovery of *vestium*.[34] However, due to the imminent war that was to overrun Poland, the claim proposed by his compatriots passed unnoticed. In 1967, the idea put forth in 1938 was again considered by other Polish chemists who hypothesized that the *vestium* isolated by Śniadecki in 1808 could have been ruthenium, a metal unknown at that time.[35] However, these nationalistic predispositions lasted only briefly. The following year, on the occasion of the bicentenary of Śniadecki's birth, Polish chemist Kazimierz Sarnecki announced after lengthy analyses and with some reluctance that, due to irreconcilable differences, *vestium* could not possibly have been ruthenium.[36]

I.2.4. ERYTHRONIUM, PANCHROMIUM, OR VANADIUM

The element with atomic number 23 that we know as vanadium was identified for the first time in 1801 by the Spanish chemist Andrés Manuel del Rio (1764–1849) while he analyzed minerals from Mexico. As with the other elements already mentioned, it is important to note several fundamental points: this discovery was made before John Dalton propounded his atomic theory between 1803 and 1808, before the formulation of the periodic table by Dmitri I. Mendeleev in 1869, and more than a century before the concept of the atomic number, elucidated largely by the work of Henry G. J. Moseley in 1913. Hence, the possible points of reference for a scientist in those far off days were fairly limited.

Del Rio was born in Madrid on November 10, 1764, and studied at the University of Alcalá de Henares, subsequently obtaining his doctorate at the Accademia Mineraria de

Almadén. He left for England in 1791, moved to France during the turbulent days of the revolution to study under Lavoisier, and finally traveled to Germany, to the renowned Royal Mining School of Freiburg in Saxony. In Germany, he established a solid and long-lasting friendship with naturalist Alexander, Baron von Humboldt (1769–1859).

In 1794, while the revolutionary winds from France were blowing strongly throughout Europe, the youthful Del Rio was named professor of mineralogy at the mining school of Mexico, which had been recently founded by the chemist Don Fausto d'Elhuyar y de Zubice (1755–1833).[37] Del Rio set sail[38] and established himself in the New World. Some years later, while examining lead-containing minerals from Zimapán, in the province of Hidalgo in central Mexico, he isolated several compounds of a substance that initially he called *panchromium*. The name quite appropriately described the multicolored salts of the new metal. Shortly afterward, the name was changed to *erythronium* (from Greek, ἐρυθρός, meaning red) due to the predominantly red color of the solutions obtained by treatment with acids. There are some doubts about the effective date of the discovery (1801 or 1802) because the original documents are no longer available, but it is clear that the brown lead-containing mineral from Zimapán was in fact vanadite: $3Pb_3(VO_4)_2PbCl_2$. The oldest document regarding *erythronium*[39] was published in the *Gazeta de México* on November 12, 1802. Del Rio[40] gave many mineral samples to his friend von Humboldt[41] when the latter visited Mexico in 1803. The German naturalist in turn sent some of these samples, together with several scientific considerations, to the Institut de France, but unfortunately they never arrived at their destination because the ship transporting them to Europe was lost.

Because the properties of *erythronium* were very similar to those of chromium, an element discovered in 1794 by the French chemist Louis Nicolas Vauquelin (1763–1829), Del Rio lost faith in his work and rejected his discovery. In 1805, the mineral suspected of containing *erythronium* was analyzed by mineralogist Hippolyte-Victor Collet-Descotils (1773–1815), a friend of Vauquelin. He erroneously concluded that Del Rio's new metal was actually basic lead chromate.[42]

A quarter of a century later, in 1830, Nils Gabriel Sefström (1787–1845) described a new element that he had found in iron deposits from Taberg, in the region of Småland, Sweden. He noted that the properties of the iron extracted from those deposits were marked by peculiar features possibly related to the presence of a new metal[43] that he immediately named vanadium after the Scandinavian divinity "gottin Freya Vanadin." A few months before the discovery of vanadium, Friedrich Wöhler (1800–82) had come close to its rediscovery,[44] but without explanation abandoned his samples and dedicated his time to other pursuits. This neglect of his experiments cost him dearly: when, in 1831, he realized that Sefström had discovered the same metal, he had no choice but to give the credit to his colleague—and immediately made his claim for Del Rio's *erythronium*. The missed opportunity must have been a cause of much frustration to him. In fact, Berzelius wrote personally to console him, emphasizing that the name Wöhler would be immortal due to his many other important discoveries.[45]

Berzelius also created an imaginative story for the public regarding the discovery of vanadium:[46] "In the distant North there lived a fascinating and gracious goddess, Vanadis. One day a person arrived at her house and knocked at the door. The goddess, who was not in a hurry, did not move and thought—they'll knock again if they want to see me—but she heard nothing. The surprised goddess asked herself, who could the mortal be that did not have the patience to knock again to meet her, and ran to the window. She