ELEMENT AND RADICAL: THE DIVERGENCE OF SYNONYMS

James Togeas, University of Minnesota, Morris

The nouns "element" and "radical" are prominent words in the chemist's vocabulary. That their meanings nowadays are radically different is a fact that is elementary to all, yet, given their prominence, it is striking that a millennium ago they were virtually synonyms. By the late eighteenth century, Lavoisier and his colleagues had assigned them different denotations. Given the fundamental status of these two words in modern chemistry, it seems of interest to sketch the synonyms' divergent histories, which are taken in this paper through the first decades of the nineteenth century. Inevitably, the evolution of words is about the evolution of ideas. In this case, it is the evolving complexity of our ideas about the fundamental nature of matter that acts as a wedge to drive their meanings apart.

Empedocles (fl. 450 BCE), the Greek natural philosopher, poet, and physician of Sicily, proposed the theory of the four elements, earth, air, fire, and water, calling them the *rhizomata*, the roots of all things (1). Plato (427-347 BCE) in his dialog *Timaeus* described an atomic theory of the elements, which he called the *stoicheia*, a Greek word for the letters of the alphabet (2). Aristotle (384-332 BCE), his protégé, adopted Plato's term. Lucretius (ca. 98-53 BCE), writing in Latin in *De Rerum Natura*, used the word *elementa* to denote both the four elements of Empedocles and the letters of the alphabet, and thus as a synonym for *stoicheia* (3). The alchemists of the medieval West apparently thought 'roots' a better metaphor than 'alphabet,' and in Latin, their scholarly language, "described their four elements as *radices*, corresponding to the Empedoclean *rhizomata* (4)." Thus, earth, air, fire, and water are variously *rhizomata* = *stoicheia* = *elementa* = *radices*. Element and radical are synonyms in the varied meanings above, in a qualitative way, as the roots or principles of things, but not, of course, in the quantitative sense of implying elemental composition.

When Aristotle posed the question as to the character of the elements, he wrote (5):

> An element, we take it, is a body into which other bodies may be analysed, present in them potentially or in actuality (which of these, is still disputable), and not itself divisible into bodies different in form.

A synonymous term for unanalyzable or indivisible body is "simple substance," which can then be added to the string of synonyms in the second paragraph. Tenney L. Davis has written about the general acceptance of this definition over the centuries (6):

> 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.

There can be no objection to Davis's view on elements as far as it goes, and yet there is another facet to the definition that is the same in Aristotle and Boyle, slightly different in Lavoisier, and has disappeared entirely from our modern thought. For convenience this will be called the postulate of universal distribution: elements are simple substances universally distributed in nature.

For Aristotle the four undecomposable bodies are universally distributed (7):

> All the compound bodies—all of which exist in the central body—are composed of all the 'simple' bodies. ...they all contain Earth...all contain Water...and they contain Air and Fire...

The version by Robert Boyle (1627-1691) is an oft-quoted definition of element, although it is not unusual to find that the concluding phrase, the one about universal distribution, has been omitted (8):

> And now to prevent mistakes, I must advertize You, that I now mean by Elements, as those Chymists that speak plainest do by their Principles, certain Primitive and Simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the Ingredients of which all those call'd perfectly mixt Bodies are immediately compounded, and into which they are ultimately resolved: now whether there be any one such body to constantly be met with in all, and each, of those that are said to be Elemented bodies, is the thing I now question.

Although Aristotle and Boyle agree on definitions, they reach different conclusions. Boyle contends that earth, air, fire, and water are not elements because they are not universally distributed. In fact, he doubts whether there are any elements at all and concludes that chemical theory must be framed as a theory of corpuscles. That, however, is aside from the main path of this article; but at this point in time there seems to be no reason to think that element and radical are not synonymous.

There is a table of thirty-three simple substances in the *Elements of Chemistry* by Lavoisier (1743-1794); of those, twenty-six appear in the modern periodic table. The table is further subdivided into four categories (9). The crucial subdivision for this discussion is that elements and radicals are intersecting subsets of the set of simple substances. In order for a simple substance to be an element, according to Lavoisier, it is (10):

> ..also necessary for it to be abundantly distributed in nature and to enter as an essential and constituent principle in the composition of a great number of bodies.

Rather than conclude like Boyle that there are no elements because there is no simple substance that obeys the strict postulate of universal distribution, Lavoisier relaxes that postulate. In order that a simple substance be termed an element, it is only necessary that it enter into "the composition of a great number of bodies." There are five simple substances "belonging to all the kingdoms of nature:" light, caloric, oxygen, azote (nitrogen), and hydrogen; and hence these are the elements. Interestingly, charcoal (carbon) fails to make the list.

A revision of chemical nomenclature accompanied the chemical revolution of Lavoisier, with the *Méthode de nomenclature chimique* appearing in 1787, two years before Lavoisier's *Traité élémentaire de Chemie*. Guyton de Morveau (1737-1816), who had written extensively on nomenclature, was senior author of *Méthode*. A central idea of the new chemistry is that, in modern terminology, acids are oxides of nonmetals. In the language of the *Méthode* oxygen is the acidifying principle, and what we term nonmetals are "acidifiable bases or radical principles (11)." The known acidifiable bases are azote, charcoal, sulfur, and phosphorus, and the unknown the muriatic, boracic, and fluoric radicals—seven altogether. As noted above, azote appears among the elements in Lavoisier's *Traité*, and hence it is the sole point of intersection of the subset of elements and subset of radical principles of acids (12). Evidently, the notion of radical still implies the meaning of root, since sulfur is that root that differentiates sulfuric acid in its combination with oxygen from phosphoric acid, for which phosphorus is the root or radical principle. It is clear that the words element and radical no longer mean the same thing: some of the simple substances are elements because of their universal distribution, whereas some of those not universally distributed—nonmetals and hence principles of acids—are designated as radicals. However, although elements are simple substances, radicals may be either simple or compound. Lavoisier summarizes the situation as follows (13):

> I have already shown, that almost all the oxydable and acidifiable radicals from the mineral kingdom are simple, and that, on the contrary, there hardly exists any radical in the vegetable, and more especially in the animal kingdom, but is composed of at least two substances, hydrogen and charcoal, and that azote and phosphorus are frequently united to these, by which we have compound radicals of two, three, and four bases or simple elements united.

The postulate of the universal or near-universal distribution of elements fades from view in the years immediately following Lavoisier's death. During these same years the notion of a radical seems to retain a fading echo, as it were, of its former status as a simple substance. In his researches on cyanogen, or the radical of prussic acid, Joseph Louis Gay-Lussac (1778-1850) observed that the radical remains unaltered through a series of reactions, and that (14)

> ..when it combines with hydrogen, shows us a remarkable example, and hitherto unique, of a body which, though compound, acts the part of a simple substance in its combination with hydrogen and metals.

The same is true of the benzoyl radical, C_7H_5O, shown by Friedrich Wöhler (1800-1882) and Justus Liebig (1803-1873) to persist unchanged through a series of chemical transformations (15). J. J. Berzelius, writing to the authors on the significance of their discovery, said that (16):

> ..the radical of benzoic acid is the first example proved with certainty, of a ternary body possessing the properties of an element.

Gay-Lussac had observed a binary radical that acts like a simple substance. Berzelius hailed a ternary radical with the properties of an element. The notion proved illusory, however, that one might prepare a table of organic radicals comprising the simple substances of organic chemistry, in analogy to Lavoisier's table of simple substances.

Among ancient writers, earth, air, fire, and water were on equal footing: each was a simple substance; each was universally distributed in nature; all lay in the hidden, tangled rhizome of things; and a string of synonyms—*rhizomata* or *radices*, *stoicheia* or *elementa*—might be used for the set. The chemistry of Lavoisier, with its list of thirty-three simple substances, was evidently more complex, and not all of the substances shared equal footing. Lavoisier used the word element for a simple substance meeting the relaxed postulate of universal distribution. Some simple substances were radicals, but not all radicals were simple substances; and only one element was also a radical. Evidently, by the time of the chemical revolution and its reformation of chemical nomenclature, element and radical were no longer synonyms.

REFERENCES AND NOTES

1. K. Freeman, *Ancilla to The Presocratic Philosophers*, Harvard University Press, Cambridge, MA, 1962, 52, and the same author's *Companion to the Presocratic Philosophers*, Harvard University Press, Cambridge, MA, 1962, 181.
2. Plato, *Timaeus,* Francis M. Cornford (trans.), Bobbs-Merrill, Indianapolis, IN, 1959, § 48c. J. R. Partington, *A History of Chemistry*, Macmillan, London, 1970, Vol. 1, 55.
3. Lucretius, *On the Nature of Things*, W. H. D. Rouse (trans.), M. F. Smith (rev.), Loeb Classical Library, Harvard University Press, Cambridge, MA, 1975. On p 68, note "a," the translator's list all of those passages where Lucretius compares the elements to the letters of the alphabet. Aristotle, *On Generation and Corruption*, Book II, H. H. Joachim (trans.), *Great Books of the Western World*, University of Chicago Press, Chicago, IL, Vol. 8, 1952. Partington, Ref. 2, pp 86-90.
4. C. G. Jung, "Alchemical Studies," R. F. C. Hull (trans.), *Collected Works*, Princeton University Press, Princeton, NJ, Vol. 13, 1967, 195. *Radix* is the Latin singular for root.
5. Aristotle, *On the Heavens*, Book III, § 3, J. L. Stocks (trans.), *Great Books* (Ref. 3). Since he believes that matter is continuous and not discrete, Aristotle will argue that the elements are present in bodies potentially, not actually. Wood remains wood at every conceivable stage of subdivision; at no point could one actually encounter earth, air, fire, and water. Hence, the elements are not present actually, but since experience shows that wood can be decomposed into them, they are present potentially.
6. T. L. Davis, "Boyle's Conception of Element Compared with that of Lavoisier," *Isis,* **1931**, *16*, 82-91 (quote from 91).
7. Ref. 3, § 8. The central body is either planet Earth or, more likely, the realm below the sphere of the moon.
8. R. Boyle, *The Sceptical Chymist*, J. Cadwell, London, 1661, Kessinger Reprint, Whitefish, MT, n.d., 350 (original pagination). For example, J. R. Partington, *A History of Chemistry,* Macmillan, London, Vol. 2, 1961, 501, omits the phrase. Boyle also writes, "I am content to tell you that though it may seem extravagant, yet it is not absurd to doubt, whether, for ought has been prov'd, there be a necessity to admit any Elements, or Hypothetical Principles, at all," ibid., 349.
9. A. Lavoisier, *Elements of Chemistry*, Robert Kerr (trans.), Dover reprint of the first English ed., 1790, New York, 1965, 175-6.
10. Quoted in H. Guerlac, *Antoine-Laurent Lavoisier: Chemist and Revolutionary*, Charles Scribner's Sons, New York, 1973, 116.
11. L. B. Guyton de Morveau, *Méthode de nomenclature chimique*, J. St. John (trans.), English ed., London, 1788; excerpted in H. M. Leicester and H. S. Klickstein, *A Source Book in Chemistry*: 1400-1900, Harvard University Press, Cambridge, MA, 1963, 184.
12. Ref. 9, p 73. Lavoisier describes azote (nitrogen) as "the base or radical of the acid which is extracted from nitre or saltpetre."
13. Ref. 9, p 191. He cites one compound radical of the mineral kingdom, viz., that of aqua regia, terming it the "nitro-muriatic radical,"(p 179). It appears to this author that the last three words in the quote should be "simple substances united."

14. J. L. Gay-Lussac, “Of Cyanogen, or the Radical of Prussic Acid,” *Ann. Chim.*, **1815,** *95*, 136-231, T. Thomson (trans.); excerpted in Leicester and Klickstein, Ref. 11, pp 301-5, quote from 305.
15. F. Wöhler and J. Liebig, “Untersuchungen über das Radikal der Benzosäure,” *Ann. Pharm.*, **1834**, *3*, 249-87; in O. T. Benfey, Ed., *Classics in the Theory of Chemical Combination*, Dover, New York, 1963, 15-39.
16. Quoted in O. T. Benfey, Ed., *From Vital Force to Structural Formulas*, Houghton Mifflin, Boston, MA, 1964, 34.

ABOUT THE AUTHOR

James Togeas is professor of chemistry at the University of Minnesota, Morris, where he teaches physical, general, and polymer chemistry and participates in the college’s honors program. He also teaches a one-semester course in the history of chemistry, for which he has written a text, *Atoms and Elements*.