ERNEST RUTHERFORD, THE "TRUE DISCOVERER" OF RADON

James L. Marshall and Virginia R. Marshall, University of North Texas, Denton

The proper recognition of the "true discoverer" of an element is not always straightforward. The recent play *Oxygen*, for example, skillfully demonstrates how claims of element discoveries may be ambiguous (1). To decide who receives the recognition of discovery, many questions are involved (2-4):

(1) Who gets prior claim, the person who first did the work or the person who first published? (2) For example, Scheele recognized oxygen before Priestley, but Priestley published first (1, 5, 6).

(2) What establishes "discovery," preparation as a compound or preparation in its elemental form? (4) For example, the reactive rare earths were "discovered" as their earths; the elemental forms were prepared decades later (3, 7).

(3) Must an element be "pure" before recognition of its discovery is made? (3) Chlorine was "discovered" by Scheele, even though his preparation must have been air mixed thinly with chlorine (3).

Figure 1. Friedrich Ernst Dorn (1848-1916), Geheimer Regierungs-Rat Professor of Friedrichs Universität, Halle (Saale). (Portrait at the University of Halle; photograph by the authors).

(4) Is it possible for a discovery to be shared by individuals who perform various "portions" of the work? For example, element-91 was first detected by Fajans (8) in 1913 ("brevium"), was later chemically separated and cataloged correctly in the Periodic Table in 1918 by Soddy and Cranston (9), and was prepared and named as protactinium in 1918 by Hahn and Meitner (10). Some references list these three groups as "co-discoverers" [*e.g.*, Weeks (11)], while others have limited lists [*e.g.*, IUPAC (4)].

(5) Is the mere suggestion (accompanied by preliminary analysis) that a new material is an element sufficient to attain credit for the discovery? Crawford and Cruikshank performed a crude analysis of "ponderous spar" (barium carbonate) from Strontian and concluded that it must be a "new earth" (12), but the careful research was done by Charles Hope in Edinburgh (13). IUPAC recognition goes to the latter (4) although various references credit the former (14) or both (15).

(6) For discoveries since the end of the nineteenth century, shall an atomic mass determination and spectral analysis be required before discovery of an element be accepted? Although these criteria have been unequivocally accepted (4), nevertheless for trace elements such as francium, technetium, or promethium, there may be exceptions, or at the very least, an understanding by the scientific world (4) that these experiments may be delayed until substantial amounts of material can be accumulated.

The discovery of radon presents an interesting case. In a recent report to the IUPAC (International Union and Pure and Applied Chemistry), it was stated (4):

> Radon was discovered in 1900 by the German chemist Friedrich Ernst Dorn. . . .

Similarly, the *Handbook of Chemistry and Physics* states (16):

> The element [radon] was discovered in 1900 by [Ernst] Dorn, who called it *radium emanation*.

Repetitions of the claim in Dorn's favor can be found throughout the literature (17), although there are a few isolated suggestions that Ernest Rutherford (18) and even the Curies should at least share the credit (19). A difficulty in assigning proper credit was recognized by Partington (20), who identified an erroneous citation by Hevesy (21). In Hevesy's paper an incorrect reference was given to Dorn's original paper (22) where radium was observed to produce an emanation; this incorrect reference was copied into all subsequent works of reference until Partington corrected the error 44 years later (20). In the meantime, Dorn's paper apparently was not widely read and its exact contents were lost in time.

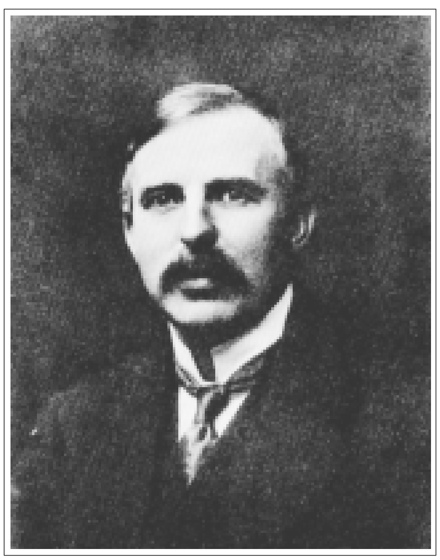

Figure 2. Ernest Rutherford (1871-1937), Macdonald Professor of McGill University, Montreal, Canada, collaborated with his colleague Frederick Soddy to develop their "transformation theory" which led to the Nobel Prize for Rutherford in 1908. (Portrait at the Dept. of Physics, McGill University; photograph by the authors).

In our current *Rediscovery of the Elements* project (23), we have frequently uncovered surprising information when investigating original sites; and we were eager to explore the story of radon. However, we were frustrated that the original article of Dorn, "Die von Radioaktiven Substanzen Ausgesandte Emanation," published in the insular journal *Abhandlungen der Naturforschenden Gesellschaft (Halle)* (22), could not be procured. We wanted to corroborate the popular account that (24):

> Like all radioactive elements, it [radium] undergoes continuous, spontaneous disintegration into elements of lower atomic weight. M. and Mme. Curie had noticed that when air comes into contact with radium compounds it, too, becomes radioactive. The correct explanation was first given in 1900 by Friedrich Dorn. . . .

We traveled to Halle (Saale) and located the journal in the Deutsche Akademie der Naturforscher Leopoldina, Emil-Abderhalden-Str. 37. The paper began with a reference to Rutherford's original discovery of the emanation (25) from thorium (22):

> Rutherford noticed that a sweeping stream of air over thorium or thorium compounds, even after being filtered through cotton, has the property of discharging an electroscope. . . . In a second work Rutherford also investigated the 'secondary activity' of the emanation [the solid material that coats the vessel walls that is formed as radon continues along its decay sequence]. . . . Rutherford said that other radioactive substances (such as uranium) did not exhibit the same properties as thorium. . . . I have adopted the approach of Rutherford and have taken a second look at other radioactive substances available locally at our Institute. . .

Dorn's paper continued with an elaborate pastiche covering uranium, thorium, radium (in the form of crude radioactive barium), and polonium (crude radioactive bismuth). Dorn repeated Rutherford's procedure, using an electrometer to detect activity, and found that indeed uranium and polonium did not display the emanation phenomenon of thorium, but that radium did. Dorn further explored the 'secondary activity,' just as Rutherford had. In his study, Dorn examined principally the influence of moisture and heat on activity. He could not find any obvious correlations, except that moisture and heat appeared to accentuate the activity. He concluded (22):

> I have not found a simple universally valid relation between the activity and

> the moisture content. . . . It appears to me that there is a strong dependence between [both] the emanation and the secondary activity upon the amount of moisture.

Dorn made no speculation regarding the nature of the emanation, except that the phenomenon apparently concerned 'a physico-chemical process.'

Figure 3. Physikalisches Institut Building of Friedrichs Universität. Ernst Dorn conducted his "radium emanation" studies on the steps of the basement of this building. (Photograph by the authors).

Dorn had stumbled onto the isotope of radon (Rn-222) (26) that was the easiest to investigate, with its "long" half-life of 3.823 days (27). The isotope that emanated from thorium (Rn-220) (26) observed by Rutherford, with its half-life of 54.5 seconds (27), was more difficult to study. [Actinium was observed by Debierne to have an analogous emanation (28), but this isotope, Rn-219 had an even shorter half-life of 3.92 second] (27). Although the nature of the emanation was not contemplated by Dorn, it certainly was by Rutherford and the Curies. By 1903 Mme. Curie stated, in the first edition of her thesis (29):

> Mr. Rutherford suggests that radioactive bodies generate an emanation or gaseous material which carries the radioactivity. In the opinion of M. Curie and myself, the generation of a gas by radium is a supposition which is not so far justified. We consider the emanation as radioactive energy stored up in the gas in a form hitherto unknown (30).

Figure 4. The Macdonald Physics Building, where Ernest Rutherford performed his work. The building is now used as a library. (Photograph by the authors).

In a private note to Rutherford, Mme. Curie suggested the phenomenon might be a form of phosphorescence (31). This "radioactive energy" was baffling; vague descriptions were offered, for example, that they were "centers of force attached to molecules of air (32)." Rutherford vigorously attacked the problem, considering explanations that included not only phosphorescence, but also deposition of gaseous ions, deposition of radioactive particles, and stray dust (31). Eventually he and his colleague Frederick Soddy were able to show that not only did the emanation pass unscathed through a physical barrier such as cotton or water, but also through chemical barriers such as P_2O_5, sulfuric acid, lead chromate, heated magnesium, and even "platinum heated to incipient fusion (33);" that it obeyed Boyle's Law, could be condensed out, and thus behaved just like a gas (34). By 1903 they could claim that the emanation must be matter in the gaseous state (35). By the next year Mme. Curie herself had been persuaded by Rutherford's contention that the radioactive emanation was a gas present in such minute quantities that it could not be detected by ordinary spectroscopic or chemical means (32).

As early as 1902 Rutherford and Soddy believed that they were dealing with a new element (36):

> It will be noticed that the only gases capable of passing in unchanged amount through all the reagents employed are the recently-discovered members of the argon family.

[Ramsay and Rutherford had discovered argon, and Ramsay had discovered the inert gases neon, krypton, and xenon during the previous decade] (37). All this research was done on the emanation from thorium. Rutherford quickly followed up with a similar study on the emanation from radium, preferred with its longer half-life and the larger quantities of emanation that could be procured. By the middle of the decade Rutherford and Soddy were able to conclude unequivocally (32) that the emanation must be a new element in the helium-argon family. In their studies they were able to give a quantitative description, with half-lives, of the decay behavior of both thorium emanation and radium emanation. Additionally, they explained that the changes of activity with different moisture content and temperatures, which had been noted by both them and Dorn in the early articles of 1900, were due to "variations in the rate of escape of the emanation into the air (38)." They noted that (32):

> It is surprising how tenaciously the emanation is held by the radium compounds….

but correctly concluded that the occlusion was physical and not chemical (38). The characterization was completed with a molecular weight determination by Ramsay and Gray (39) that placed the element below xenon in the periodic table, and with the acquisition of a spectrum (40) with "bright lines analogous to the spectra of the inert gases (32)." With the understanding that radium produced the gaseous emanation by the expulsion of a helium nucleus (which had been isolated and identified), the phenomenon of emanation and the nature of the emanation product were completely understood (32). Rutherford had always preferred to call the element "emanation," but Ramsay did not hesitate to propose and to use the name "niton (41)."

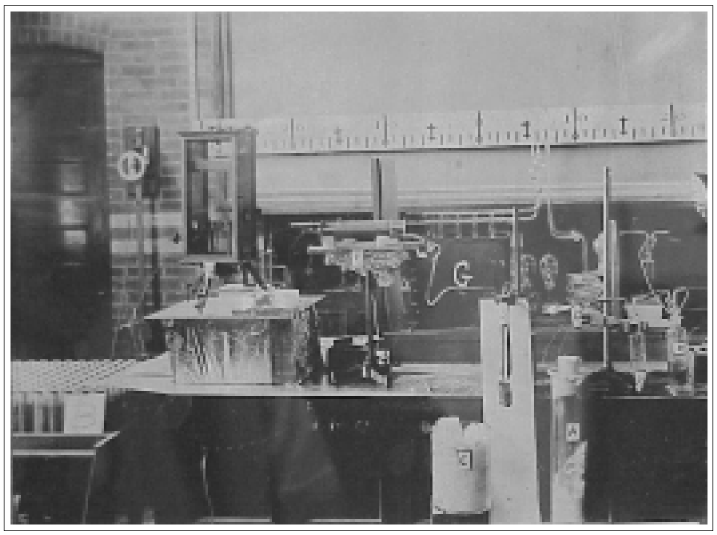

Figure 5. The original apparatus used by Rutherford in the Macdonald Building to demonstrate the nature of the thorium emanation: "Public demonstration of the Rutherford experiment on the condensation of radium emanation when passed through a copper spiral cooled in liquid air. Macdonald physics lecture room, 6 Nov. 1902." The copper spiral and ionization chambers are preserved in the Case "B" of the Rutherford Museum. (Courtesy, Rutherford Museum, Department of Physics, McGill University).

Meanwhile, what was Dorn's activity regarding emanation? His subsequent research on the subject produced only two graduate dissertations on the subject. The first (42) in 1903 dealt with the determination of diffusion constants of the "radium emanation" in salt-water solutions and toluene/water solutions. The dissertation reported only data and conclusions concerning behavioral patterns. The *only* comment made regarding the nature of the phenomenon included these three sentences (42):

> From radium comes an emanation, that behaves as if it holds a gas of high molecular weight. The emanation creates an unstable material, that leads to further changes. . . . We accept the view of Rutherford and the Curies [regarding the nature of the emanation].

The second dissertation (43), 11 years later in 1914, dealt with the diffusion of radium emanation in gelatins, again with no interpretation (44).

By the 1920s the literature was filled with a mélange of names for the radioactive gaseous element, including niton (Nt) [niton was the "official" entry in *Chemical Abstracts*], emanation (Em), radon (Rn), thoron (Tn), actinon (At), and, of course, "radium emanation." A reader of the literature was not sure whether one was dealing with the general element or with a specific isotope. In 1923 the International Committee on Chemical Elements noted that (26):

> The Committee has found it necessary to modify the nomenclature of several radioactive elements. . . Radon replaces the names *radium emanation* and *niton*.

By then Rutherford was no longer conducting research on radon and certainly was not involved with the naming of the element (45). He had moved on to other work at Manchester University (1907-1918), where his famous α-particle scattering research was performed (46), and then on to Cambridge University (1919-1937) to study the artificial disintegration of the elements (46). Unfortunately, the name "radon" was accompanied with misleading connotations, and errors have passed into historical accounts. It is interesting to note, for example, that in Dorn's article on emanation (22) he *never* used the term "radium emanation" as stated in the literature (47). He simply reiterated Rutherford's term "emanation," referring to any radioactive species that exhibited the behavior. A careful examination of the literature makes it clear that Rutherford not only proposed the name emanation (25), but also was the first to use and to propose the term radium emanation (48):

> The term emanation X, which I previously employed . . . is not very suitable, and I have discarded it in favor of the present nomenclature [radium emanation], which is simple and elastic.

As another example, the statement that "Professor Dorn showed that one of the disintegration products is a gas (24)" is incorrect. He had no inkling what he was dealing with, which is clear from his record (22, 42, 43). It would therefore appear that, by all valid criteria (1)-(6) listed above, Rutherford should be given credit for the discovery of radon: he made a full characterization of the emanation—chemical, physical, and nuclear; he proposed it to be a new element and correctly placed it in the appropriate family of the periodic table [although he utilized molecular mass and spectral data of others to corroborate his conclusions] (49).

Figure 6. Case "B" of the Rutherford Museum, being presented by Dr. Montague Cohen, past curator of the museum. The exhibits in the museum include Rutherford's apparatus in six different cabinets: A, "Nature of the α-rays"; B, "Emanations from thorium and radium"; C, "Excited radioactivity"; D, "Ionization studies"; E, "Heating effects of radiation"; F, "The radium decay series." Also in the museum are documents on a center table and his desk. The museum is in the Ernest Rutherford Physics Building of McGill University. (Photograph by the authors).

Dorn, on the other hand, had no idea of—nor any curiosity about—the nature of emanation. The *only* claim that Dorn would have to discovery is that he first noticed emanation from radium. But as is clear from the literature, the first emanation—i.e., any isotope of radon—was actually observed by Rutherford, and this was acknowledged by Dorn (22). Any claim that Rutherford and Soddy arrived at their conclusions by working with *Dorn's* compound (emanation from radium) is rendered moot by the fact that they had performed experiments on *thorium* emanation *first* and showed it was a chemically inert gas of high molecular weight, and probably belonged to the helium-argon family (32)—all before they performed the same studies on emanation from *radium* (33).

It is particularly fitting that Rutherford be credited with the discovery of the element that launched him on his long and rewarding investigations of nuclear transformations. The only question is whether Frederick Soddy, who accompanied Ernest Rutherford in the research at McGill University after Rutherford's original discovery of thorium emanation, should also share in the honors. Ramsay once suggested (40) that Soddy's rapid change of posts might have prevented his receiving due credit for certain discoveries (50); he certainly was invaluable to Rutherford at a critical time (51):

> . . . the Fates were kind to Rutherford. He was left in Canada to discover that his collaboration with a young Oxford chemist, Frederick Soddy, was to mean more to him at that precious juncture than any Chair in Europe.

Rutherford also once stated in a letter that Soddy should share whatever credit existed for their work at McGill University (52). After Rutherford's original observation of thorium emanation (25), both he and Soddy journeyed together down the fascinating path that led them to their final understanding—to the ultimate discovery—that they had found a new element created by a transmutation process, a theoretical idea discarded since medieval times. Oliver Sacks gives an absorbing account of this turning moment of chemical history in his *Uncle Tungsten* (53):

> The Curies (like Becquerel) were at first inclined to attribute [radium's] "induced radioactivity" [in everything around them] to something immaterial, or to see it as "resonance," perhaps analogous to phosphorescence or fluorescence. But there were also indications of a material emission. They had found, as early as 1897, that if thorium was kept in a tightly shut bottle its radioactivity increased, returning to its previous level as soon as the bottle was opened. But they did not follow up on this observation, and it was

> Ernest Rutherford who first realized the extraordinary implication of this: that a new substance was coming into being, being generated by the thorium; a far more radioactive substance than its parent. Rutherford enlisted the help of the young chemist Frederick Soddy, and they were able to show that the "emanation" of thorium was in fact a material substance, a gas, which could be isolated. . . . Soddy [wrote later]. . . "I remember quite well standing there transfixed as though stunned by the colossal impact of the thing and blurting out. . . . 'Rutherford, this is transmutation.' Rutherford's reply was, 'For Mike's sake, Soddy, don't call it *transmutation*. They'll have our heads off as alchemists.'"

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REFERENCES AND NOTES

1. C. Djerassi and R. Hoffman, *Oxygen*, Wiley-VCH, Weinheim, FRG, 2001.
2. B. P. Coppola, *The Hexagon of Alpha Chi Sigma*, **2001**, *92*, No. 2 (Summer), 18-19.
3. P. Walden, "The Problem of Duplication in the History of Chemical Discoveries," *J. Chem. Educ.*, **1952**, *29*, 304-307.
4. "History of the Origin of the Chemical Elements and Their Discoverers," N. E. Holden, BNL-NCS-68350-01/10-REV, prepared for the 41st IUPAC General Assembly in Brisbane, Australia, June 29th-July 8, 2001, research carried out under the auspices of the US Department of Energy, Contract No. DE-AC02-98CH10886. This document may be obtained from the Brookhaven National Laboratory Library, Upton NY, 11973, or may be downloaded from http://www.pubs.bnl.gov/pubs/documents/22575.pdf (last accessed 02/17/03). Although prepared by the IUPAC to give a current understanding of the discoveries of all elements, there is no "official" IUPAC position on the discoverers of various elements except for recent controversies over some of the transuranium (artificial) elements (N. E. Holden, private communication).
5. J. R. Partington, *A History of Chemistry*, Macmillan, London, 1964, Vol. 3, 224-225, 256-260.
6. J. E. Jorpes, *Bidrag Till Kungl. Svenska Vetenskapsakademiens Historia VII, Jac. Berzelius* (English translation by Barbara Steele), Regia Academia Scientiarum Suecica, Almquist & Wiksell, Stockholm, 1966, 18.
7. Ref. 5, Vol. 4, p 149.
8. K. Fajans and O. H. Göhring, "Ueber das Uran X_2-das neue Element der Uranreihe," *Phys. Z.*, **1913**, *14*, 877-84.
9. F. Soddy and J. A. Cranston, "The Parent of Actinium," *Proc. R. Soc,. London*, **1918**, *94A*, 384-404.
10. O. Hahn and L. Meitner, "Die Muttersubstanz des Actiniums, ein Neues Radioaktives Element von Langer Lebensdauer," *Phys. Z.*, **1918**, *19*, 208-218.
11. M. E. Weeks, *Discovery of the Elements*, Journal of Chemical Education, Easton, PA, 1968, 7th ed., 792
12. A. Crawford, "On the Medicinal Properties of the Muriated Barytes," *Medical Communications (London)*, **1790**, *2*, 301-59.
13. T. C. Hope, "Account of a Mineral from Strontian and of a Particular Species of Earth which it Contains," *Trans. R. Soc., Edinburgh*, **1798**, *4*, (2), 3-39.
14. *CRC Handbook of Chemistry and Physics*, R. C. West, Ed., The Chemical Rubber Publishing Company, CRC Press, Inc., Boca Raton, FL, 64th ed., 1984, B-33.
15. Ref. 11, pp 491-495.
16. For example, Ref. 14, p B-28. In earlier versions, the wording is different: "Discovered in 1900 by Dorn and called radium emanation. . . ." (e.g., *Handbook of Chemistry and Physics*, C. D. Hodgman and H. N. Holmes, Ed., Chemical Rubber Publishing Co., Cleveland, Ohio, 1941, 300).
17. Ref. 5, Vol. 4, p 941.
18. D. Wilson, *Rutherford*, MIT Press, Cambridge, MA, 1983. "Rutherford with Soddy had discovered new gases radon and thoron (p 395." Ambiguously, however, "Radium emanation was discovered by Dorn (p 143)."
19. A search of the Internet shows >90% of the sites repeat Dorn is the discoverer of radon. Occasionally a reference will attempt to give at least partial credit to Ernest Rutherford, e.g., *Nobel e-Museum* (http://www.nobel.se/chemistry/laureates/1908/rutherford-bio.html, last accessed 02/16/03) states that Rutherford discovered an isotope of radon; *Radon.com* (http://radon-facts.com/, last accessed 02/16/03) speculates whether Ernest Rutherford should share the credit; *Encyclopedia.com* (http://www.encyclopedia.com/html/r1/radon.asp, last accessed 02/16/03) states Rutherford and Dorn discovered different isotopes. D. J. Brenner, *Physics, Biophysics, and Modeling, "Rutherford, the Curies, and Radon"*

(http://cpmcnet.columbia.edu/dept/radoncology/crr/reports2000/a.pdf, last accessed 02/16/03) implies that the Curies should be given partial credit for first noticing that radium imparts radioactivity to surrounding air.

20. J. R. Partington, "Discovery of Radon," *Nature*, **1957**, *179*, 912. When referencing Dorn's paper, Rutherford (Ref. 32, p 70) used his abbreviated format (viz., "Dorn: Naturforsch. Ges. für Halle a. S., 1900"); hence, Hevesy's (and not Rutherford's) citation was the one copied in subsequent years.
21. G. von Hevesy, "Die Eigenschaften der Emanationen," *Jahrb. Radioakt. Elektron*., **1913**, *10*, 198-221. In this paper Hevesy gives credit to Rutherford (Ref. 25 of the current paper) and Owens (R. B. Owens, "Thorium Radiation," *Philos. Mag*., **1899**, *48*, 360-387) for the first recognition of emanation: "Von den kurzlebigen Radioelementen sind die Emanationen im Laufe der zwölf Jahre, die seit der Entdeckung [ref] der zuerst erkannten, der Thoriumemanation, verflossen sind, am erfolgreichsten untersucht worden." The only citation to Dorn in Hevesy's paper is shared with work of Rutherford, and of Ramsay, in reference to unsuccessful attempts to make compounds of the emanation: "Versuche, die Emanationen in Verbindungen zu zwingen, scheiterten gänzlich [ref]." As mentioned in Ref. 20, Hevesy=s reference to Dorn was incorrect (mistakenly written as (*Abh. Naturf. Ges. (Halle)*, 1900, *22*, 155).
22. E. Dorn, "Die von radioaktiven Substanzen ausgesandte Emanation," *Abhandlungen der Naturforschenden Gesellschaft (Halle)*, **1900**, *23*, 1-15. All translations were made by the authors.
23. "Rediscovery of the Elements," *The Hexagon of Alpha Chi Sigma*, articles found in 2000-2002 issues. Introductory article: J. L. Marshall and V. R. Marshall, *The Hexagon of Alpha Chi Sigma*, **2000**, *41*, No. 3, 42-45.
24. Ref. 11, p 785. Weeks gave an incomplete reference (Ref 37, p 811) to Dorn's paper (without volume number or pagination), similar to Rutherford's abbreviated format (see our Ref. 20). The disparity between Weeks' account and the content of Dorn's paper is suggestive that Dorn's paper was not available for study.
25. E. Rutherford, "A Radio-active Substance Emitted from Thorium Compounds," *Philos. Mag*., **1900**, *49*, 1-14.
26. F. W. Aston, G. P. Baxter, B. Brauner, A. Debierne, A. Leduc, T. W. Richards, F. Soddy, and G. Urbain, "Report of the International Committee on Chemical Elements," *J. Am. Chem. Soc*., **1923**, *45*, 867-874.
27. Ref 14, p B-298.
28. A. Debierne, "Sur l'émanation de l'actinium," *C.R. Hebd. Séances Acad. Sci., Ser. C.,* **1904**, *138*, 411-414.
29. Ref. 5, Vol. 4, p 942.
30. M. S. Curie, "Radio-active Substances," *Chem. News J. Ind. Sci*., **1903**, 235-236.
31. E. Rutherford, "Radioactivity Produced in Substances by the Action of Thorium Compounds," *Philos. Mag*., **1900**, *49*, 161-192.
32. E. Rutherford, "The Radium Emanation," in *Radioactive Transformations*, Yale University Press, New Haven CT, 1906, Ch. III, 70-94 (alternate publisher: Charles Scribner's Sons).
33. E. Rutherford and F. Soddy, "Comparative Study of the Radioactivity of Radium and Thorium," *Philos. Mag*., **1903**, *5*, 445-457.
34. E. Rutherford and F. Soddy, "Note on the Condensation Points of the Thorium and Radium Emanations," *Proc. Chem. Soc., London*, **1902**, 219-220.
35. E. Rutherford and F. Soddy, "Condensation of the Radioactive Emanation," *Philos. Mag.*, **1903**, *5*, 561-576.
36. E. Rutherford and F. Soddy, "Cause and Nature of Radioactivity. II," *Philos. Mag.*, **1902**, *4*, 569-585.
37. Ref. 5, Vol. 4, 1964, pp 916-918.
38. Ref. 32, Ch. II, pp 37-69, "Radioactive Changes in Thorium."
39. W. Ramsay and R. W. Gray, "La densité de l'emanation du radium," *C.R. Hebd. Séances Acad. Sci., Ser. C.,* **1910**, *151*, 126-128.
40. W. Ramsay and J. N. Collie, "The Spectrum of Radium Emanation," *Proc. R. Soc., London*, **1904**, *73*, 470-476.
41. W. Ramsay, *The Gases of the Atmosphere*, Macmillian, London, 4th ed., 1915, 283.
42. F. Wallstabe, "Untersuchungen über die Emanation des Radiums," Inaugural Dissertation, Friedrichs Universität, 1903, 11.
43. A. Jahn, "Über Diffusion von Radium Emanation in wasserhalitige Gelatine," Inaugural Dissertation, Friedrichs Universität, 1914, 306. The only statements regarding the nature of the emanation include "The radium emanation is a high-molecular gas. . . .that results when a radium atom undergoes alpha decay" and a reference to Rutherford, 1913, who discussed emanation and "Ra-A" [the decay product resulting from radon].
44. A biography of Dorn (1848-1916) [*100 Jahre Gebäude des Physikalischen Instituts in Halle—Die hallesche Physik am Ausgang des 19. Jahrhunderts*, Martin-Luther-Universität Halle-Wittenberg Wissenschaftliche Beiträge 1990/33 (O32), Halle (Saale), 1990, 22-32] paints a picture of a "Renaissance Man" who dabbled in various projects. His dissertation from Königsberg in 1871 was concerned with theoretical transformations of elliptical integrals ("Über eine Transformation 2.Ordnung welche das elliptische Integral mit imaginärem Modul auf ein ultraelliptisches mit reellem Modul reducirt"). He measured the temperature at various depths in the earth. He was involved in an International Congress on the precise determination of the value of the ohm, the unit of electrical resistance (H. Helmholtz, "Über die elektrischen Maßeinheiten nach dem Beratungen des elektrischen Kongresses, versammelt zu Paris 1881," Vörtrage und Reden, Braunschweig, Bd. 2, 1903, 295). Upon the discovery

of X-rays in 1895, he immediately initiated investigations of their physiological and physical effects (E. Dorn, "Sichtbarkeit der Röntgenstrahlen für Vollkommen Farbenblinde, *Ann. Phys.*, **1898**, *66*, 1171). Dorn worked on liquid crystals with Daniel Vörlander, the well known pioneer in that science (D. Vorländer, *Chemische Kristallographie der Flüssigkeiten*, Leipzig, 1924). He studied electrical effects of radioactive substances (mainly radium) (E. Dorn, "Elektrisches Verhalten der Radiumstrahlen im Elektrischen Felde," *Phys. Z.*, **1900**, *1*, 337), and various other electrical-mechanical studies at the Physikalisch-Technische Reichsanstalt (Physico-Technical Testing Office) of Berlin, where Werner Siemens had established a standard unit of resistance (W. Siemens, "Vorschlag eines Reproduzierbaren Widerstandsmaßes," *Ann. Phys.*, **1860**, *110*, 1). [The Reichsanstalt of Berlin was the same establishment where the discoveries of rhenium and "masurium" were later announced by W. Noddack, I. Tacke, and O. Berg (—, *Nature*, **1925**, *116*, 54-55.)] After intermediate appointments at Greifswald as Privatdozent (1873), Extraordinarius für Physik at the Universität Breslau (1873-1880), and Professor ordinarius at the Technische Hochschule Darmstadt (1881-1886), Dorn joined the Direktorat des Physikalischen Laboratoriums of Friedrichs Universität in Halle in 1886 ("Friedrichs Universität" was changed to its modern name Martin-Luther-Universität Halle-Wittenberg in 1946). In 1895 he became Direktor of the Physikalisches Institut and was well known for the rigorous curriculum he developed there. Upon his death a somber memorial was written (A. Wigand, "Ernst Dorn," *Phys. Z.*, **1916**, *17*, 299). Although he developed an impressive reputation at Friedrichs Universität, his name is not well known in science in general, probably because his approach to scientific research was mainly applied, rather than basic.

45. However, Mme. Curie and E. Rutherford were consulted and they approved the names for the three isotopes radon, thoron, and actinon (Ref. 26). In the few years previous, Marie Curie, wishing to control decisions on nomenclature along with Rutherford, had proposed various names, such as "radioneon" and "radion," but Rutherford politely turned down the honor of christening element number 86. The scientific world continued to use the names then currently in vogue. (Ref. 18, p 431).
46. A. S. Eve, *Rutherford,* Macmillan, New York, 1939.
47. Ref 14, p B-28. This reference erroneously claims that Dorn even *originated* the term "radium emanation."
48. E. Rutherford, "Slow Transformations of Products of Radium," *Philos. Mag.*, **1904**, *8*, 636-650.
49. F. Soddy, *The Interpretation of Radium and the Structure of the Atom*, Putnam, New York, 4th ed., 1922.
50. "Mr. Soddy collaborated in the experiments preliminary to the successful mapping of the spectrum; had he not been obliged to leave England, he would, no doubt, have shared whatever credit may attach to this work." (Ref. 40, p 476). Before Soddy procured his permanent post at the University of Glasgow in 1904, where he performed his isotope research leading to his Nobel Prize, in rapid succession he was an Oxford Fellow 1898-1900, then a Demonstrator in the Chemistry Department at McGill University 1900-1902, collaborating with Rutherford, October, 1901-April, 1903, and finally moving on to work with Ramsay on the spectrum of radon 1903-1904 (Ref. 51, pp xv-xvi).
51. G. B. Kauffman, Ed., *Frederick Soddy (1877-1956)*, D. Reidel, Boston, MA, 1986, xiv.
52. There is no evidence that Rutherford made a claim for the discovery of radon; hence, there would be no appropriate moment for him to "share the honors" with Soddy. Rutherford *did* support Soddy throughout his career, recommending him for election to the Royal Society and for the Nobel Prize (Ref. 18, p 240). Concerning the collaborative work at McGill University, "Rutherford, in writing a reference for Soddy who was applying for a post in Glasgow, insisted that it had been a partnership of equals from which any credit should be equally shared." (Ref. 18, p 164).
53. O. Sacks, *Uncle Tungsten*, Alfred A. Knopf, New York, 2001, 282.

ABOUT THE AUTHORS

J. L. Marshall obtained his Ph.D. in organic chemistry from Ohio State University in 1966 and V. R. Marshall her M. Ed. from Texas Woman's University in 1985. JLM has been Professor of Chemistry at the University of North Texas, Denton, TX 76203-5070, since 1967, with an intermediate appointment (1980-1987) at Motorola, Inc. V. R. M. teaches computer technology in the Denton School system. Since their marriage in 1998 the two have pursued their ten-year project, "Rediscovery of the Elements."