Book Review

A Brief Account of Radio-activity

Francis P. Venable, Ph.D., D.Sc., LL.D., D. C. Heath & Co., 1917, 54 pages.

Reviewed by Julian Bullitt*

With this review we initiate what is intended to be a series of occasional reviews of 'Great Books' , vintage chemistry books (texts or monographs) that were pioneering in their approach to chemistry or have had a significant impact on generations of chemists. We invite our readers or prospective reviewers to contact us with suggestions for future reviews. Please, include the author, title, publisher and approximate date of publication, along with a brief explanation of the book's importance.

Please submit your ideas to Dennis Sardella at: sardella@bc.edu.

My niece and nephew gave me a small book this summer—*Radio-activity* by Francis P. Venable. I found it fascinating as a historical snapshot of the knowledge of radioactivity twenty years after its discovery, and of atomic structure during the quantum revolution. My father James Bell Bullitt, Jr. (1906–1957) signed the book "J. B. Bullitt, Jr, U.N.C, Chapel Hill, N.C., March 1923." He would have used the book as a freshman at North Carolina studying general chemistry, probably under Professor Venable. He earned a B.S and M.S in chemistry at Chapel Hill. I expect that he gave it to my sister when she was studying freshman chemistry in 1956–1957. I wrote this review for members of my family most of whom are not scientists.

Radio-activity was prepared to supplement a class in general chemistry in the early part of the twentieth century. "Such a course dealing with the composition and structure of matter is left unfinished and in the air, as it were, unless the marvelous facts and deductions from the study of radio-activity are presented and discussed." It gives the basics of the field that college freshmen or "busy men in other branches of science" might wish to know in the midst of a revolutionary period in physics and chemistry.

———————————-

* Julian Bullitt retired from Polaroid Corp after 27 years in various technical positions, most recently as a Research Fellow and Director of the Image Science Laboratory. He has an A. B. from Princeton University and a Ph. D. in Inorganic Chemistry from M. I. T.

Recognizing that the description he is giving was incomplete, Venable emphasized experimental data over theory. "Theories cannot be avoided, but the facts remain while theories grow old and are discarded for others more in accord with the facts." Venable (1856-1934), Professor of General, Analytical and Applied chemistry at the University of North Carolina, was chairman of the Chemistry Department, president of the University from 1900 to 1914, and president of the American Chemical Society. He authored other books including *A Short History of Chemistry* and *Periodic Law*. He consulted for Thomas Willson and James Morehead on an electric furnace product that proved to be calcium carbide and the gas it evolved with water was acetylene. Both Willson and Morehead subsequently made fortunes from acetylene, and their manufacturing process eventually gave birth to Union Carbide.

Radio-activity consists of six short chapters: *Discovery of Radio-activity, Properties of the radiations, Changes in radio-active bodies, Nature of the Alpha Particle, Structure of the atom* and *Radio-activity and Chemical Theory*.

Chapter One describes the discovery of X-rays by Roentgen (1895)**,** and the discovery by Becquerel (1896) that uranium and thorium would also expose photographic plates. Marie. Curie noted that a large number of minerals containing uranium or thorium were much more active than the pure elements, and she and her husband Pierre Curie subsequently iso- lated various active fractions from pitchblende, UO_2. One very active substance isolated was named polonium. Another substance isolated with barium salts was named radium. The Curies also determined that the lead found in pitchblende was radioactive and that it had a different atomic weight than ordinary lead. *(actually, the end-product of uranium-238 decay is stable* Pb^{206}*, ed.)*

Chapter Two describes alpha, beta and gamma radiation and the devices used to measure them**,** including the Wilson cloud chamber. Alpha rays were described as having a positive charge and seeming to be positive ions. Beta rays are negatively charged and "are identical with the cathode rays and are negative electrons." Electrons are always described in the book as "negative electrons." Gamma rays are not deflected by magnetic fields and appear "analogous to the X rays and are of the order of light**,**" but substantially more penetrating than X-rays. We, of course, understand today that gamma rays typically have 100 times the energy of X-rays.

Chapter Three describes the different substances that can be extracted from uranium and thorium salts. Radioactivity in rubidium and potassium is noted but "the last two, while feebly active themselves, do not form any secondary radio-active substances, as far as is known." Some of the new elements are described as having chemical properties identical to those of a known element but differing only in atomic weight. Venable also describes the uranium, thorium and actinium decay series.

Chapter Four discusses the nature of the alpha particle. It is positively charged, with twice the charge of the electron, an atomic weight of four, and forms helium atoms.

Chapter Five introduces the structure of the atom by describing the properties of the newly discovered element radium, what we describe today as the isotope Ra^{226}. Venable notes that the alpha particle emissions from radium chemicals

> "produce marked chemical effects on a number of substances," including the decomposition of water into hydrogen and oxygen. Radium alpha particle emissions generate an amount of heat noted to be much in excess of that from the combustion of hydrogen. "Such a production of energy so far passes all experience that it becomes almost inconceivable." Rutherford "offered the hypothesis that the atoms of certain elements were unstable and are subject to disintegration." Rutherford's atomic description is next introduced—
>
>> "a central charge of positive electricity surrounded by a number of rings of negative electrons. ... The central system of the atom is from some unknown cause unstable, and one of the helium atoms escapes from the central mass as an alpha particle." "In this picture energy and matter lose their old- time distinctness of definition."

This is presumably an oblique reference to the theory of relativity. On discussing Rutherford's alpha scattering experiments, Venable points out that

> "the central charge in an atom corresponds to about one-half the atomic weight multiplied by the charge on an electron."

Chapter Six describes how radioactivity might help enhance chemical theory. In particular Venable illustrates how the periodic system can be better understood by not arranging the elements according to their atomic weight but rather by the then-new concept of atomic number. Moseley's data on the X-ray spectra of the elements could be explained by "a fundamental quantity which increases in units from one element to the next." Using this explanation**,** Venable shows how the decay of uranium by the emission of eight alpha particles eventually produces lead. The problem noted is that the resulting lead appeared to have an atomic weight of 207.17, while this model predicts an atomic weight of 206. "It is known only that the end product would probably be some element closely resembling lead chemically and hence difficult or impossible to separate from it." The stable lead- like decay product of thorium has an atomic weight of 208.4. Venable next describes the work of Frederick Soddy in rationalizing the decay series described in Chapter Three by postulating a number of species with differing atomic weights but with identical chemical properties and atomic spectra. "Soddy has suggested the word *isotope* for the element and *isotopic* for the property, and these names have come into general use."

The quantum revolution began in 1900 with a paper by Max Planck, who had been warned as a student that physics was a closed subject and that no more important discoveries would be made. Planck described the radiation spectra of black bodies by requiring that these thermal oscillators behaved as if they were restricted to discrete energy levels ($E = nh,$ where n is an integer, h is now known as Planck's constant, and is the oscillator frequency). In 1905 Albert Einstein wrote three important papers: one a statistical mechanical explanation of Brownian motion, the second proposing the special theory of relativity, and the third on the photoelectric effect. To describe the photoelectric effect, Einstein postulated that light consists of a beam of corpuscles of energy h. When a metal absorbs a corpuscle, an electron would gain that energy. This approach explained the data well.

At the same time, experimental physicists from the English school described the properties of the atom, but without a satisfactory theoretical explanation. J.J. Thomson (1897) dis- covered the electron. When Thomson measured the mass of the electron as one two-thousandth of the mass of the hydrogen atom, it became clear that the atomic mass was associated with the positive charge. Ernest Rutherford studied the scattering of alpha particles by thin metal foils. Rutherford (1911) postulated that the atom had its positive charge and essentially all of its mass concentrated in a small region, now called the nucleus. The electrons needed to balance that nuclear charge were presumed to be distributed uniformly on the surface of spheres of atomic dimensions like a miniature solar system. Electromagnetic theory predicted that the Rutherford atom to be unstable, with the electrons eventually spiraling into the nucleus while emitting light.

This quandary led Niels Bohr (1913) to describe the spectra of the hydrogen atom by postulating that the angular momentum of the electron was quantized in units related to Planck's constant h. The energy is then quantized again as $E = h$. There was no understanding why quantization is required, but the Bohr atom and its enhancements did explain the atomic emission spectra as well as the photo-electric effect. It was not until Louis de Broglie, Erwin Schroedinger, and Werner Heisenberg proposed quantum mechanics during the period 1923- 1926 that quantization became understood.

The following web site has more on radioactivity and atomic structure:

http:/http://dbhs.wvusd.k12.ca.us/ ChemTeamIndex.html

This 1917 book was written for a freshman chemistry class. As a result *Chapter Six* focuses on the periodic table. Venable introduces a number of new and revolutionary concepts: the Rutherford atom (1911) and how that describes the alpha particle scattering. Both Moseley's 1913 work on X-ray spectra and Soddy's 1913 rationalization are used to base the periodic table on atomic number rather than atomic weight. The Bohr atom (1913) is not mentioned since it does not add to the discussion, other than in replacing the unstable Rutherford atom with another model whose stability is *ad hoc*; furthermore, the quantum concept was quite speculative in 1917. The quantum mechanical basis of the periodic table had to wait for another decade for the Schroedinger wave equation of 1926.

Uranium is known, but only as the isotope U^{238}. Venable hypothesizes U^{234} as a decay product. U^{235}, present at only 0.7%, was then unknown. Its separation from U^{238} would have to wait until the 1940s. As a result, Soddy and Venable could not explain the source of the actinium alpha decay series that we now know originates with U^{235}.

In 1917, the only radioactivity known was the result of the uranium, thorium and actinium alpha particle decay series, with the two exceptions noted in *Chapter Three* — rubidium and potassium. K^{40} and Rb^{87} are products of uranium fission. This is the only evidence presented that requires the other decay mechanism – nuclear fission – that was discovered in 1938.

Venable acknowledges in the *Preface* his "obligations to Professor Bertram B. Boltwood for his helpful suggestions." Boltwood (1870-1927), a physicist at Yale, identified a number of the intermediate decay products in the uranium and actinium decay series and suggested dating minerals by the ratio of uranium to lead. I am surprised that his work on isolating ionium, now known as Th^{230}, is not mentioned.

Professor James Jorgenson, chair of the chemistry department of Carolina, noted

> "It astonishes me to see what was known about radioactivity at the time of the book's printing in 1917. Even more astonishing is Venable's detailed knowledge of the topic, his understanding of atomic theory, and the connections he makes with periodicity."

There is further evidence of the advanced nature of *Radio-activity* relative to another text in use at that time. I have my father's copy of the 1923 edition of *Chemical Principles* by Arthur A. Noyes and Miles Sherrill, 1923. He used it in the fall of 1925 in Chem 83, Advanced Physical Chemistry. This text was in active use at MIT for more than fifty years – in 1966 my wife used the 1938 edition in a graduate level Chemical Thermodynamics course. Page 95 of the 1923 edition has a section on the relation of atomic weights to the periodic law that the 1938 edition omits.

> "When the elements are arranged in the order of the so determined atomic weights, it is found that there is a progressive change in the various properties

> of the elementary substances and their compounds and a periodic recurrence of similar properties."

Remarkably, Venable introduced atomic number to freshmen whereas Noyes did not mention it six years later in a text aimed at "junior, senior or graduate students in physical chemistry." Noyes, of course, was one of the preeminent physical chemists of that era. In 1903 he created and directed the Research Laboratory of Physical Chemistry at MIT until he went west as one of Caltech's founding "big three" in the early 1920s.