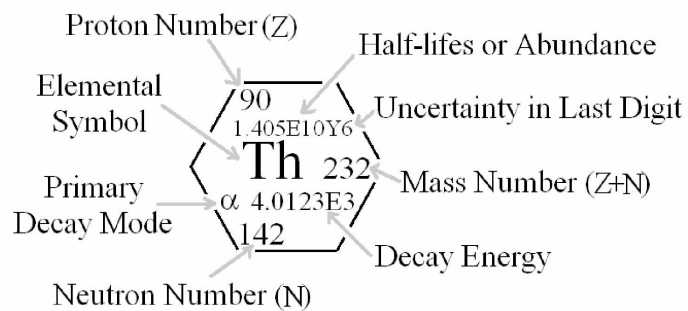
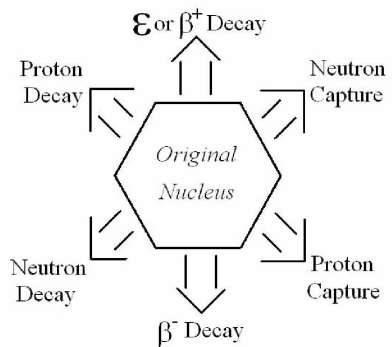


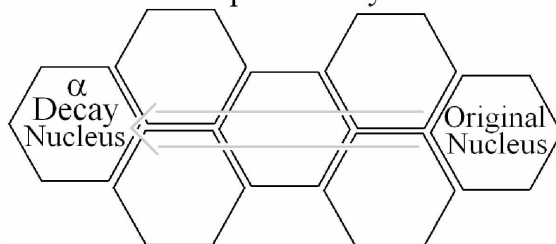
TRILINEAR CHART LAYOUT & DECAY MODES



Decay and Activation Modes



Alpha Decay



THE FOUR NATURAL DECAY SERIES

Introduction

Initially radiochemists were interested in unraveling three decay series. These three distinct decay chains were considered to be: uranium, radium and thorium. Additionally, all radioactive nuclides were considered as new elements. Each of these decay series began with a long-lived parent. The radioactive isotopes were originally called *radioelements*. Additionally, labels were attached for these decay products, (i.e. UX, ThX, RaA, RaB etc.)

In 1905 all decay was considered to be by alpha emission which of course led to an impossibility since some daughters were found to be identical to their parent. The three natural decay series became two series in 1907 when radium and uranium were found to be related. Actinium was already replacing radium as the third series. The term "isotope" was first used in 1913 by Soddy Frederick to describe nuclides which occupy the same position in the Periodic Table but which differ in their nuclear properties. Thomson (1913) later showed the element neon to be made up of more than one isotope. In 1919 Francis Aston constructed a mass spectrograph capable of use in the discovery of virtually all elements. But it was not until 1925 before the existence of oxygen of mass 17 was first observed¹. Later on, oxygen-18 and 17 were discovered in natural material². Urey in 1931 discovered the hydrogen isotope of mass 2 (called deuterium) and estimated its natural concentration^{3,4}. The discovery of the neutron in 1932 led to a plethora of bombardment experiments that eventually led to the discovery of fission in 1939 and the transuranics in 1941 which in turn led to the fourth decay series (one that is not found in nature). It can be said that the first half of *the nuclear century* began with a mild intellectual aberration in Paris and led to the first nuclear detonation in New Mexico.

Unraveling the Four Decay Series

There were many steps in unraveling the decay series. However there are 12 that stand out as significant:

1. Becquerel's discovery marks the beginning of the nuclear age in 1896.
2. The hunt for all things radioactive began in earnest in 1898 with the discovery by the Curies of polonium and radium (named after her home country and because it gave off so many rays – hence "ray-dium").
3. In 1899 Schmidt showed that thorium was also radioactive.
4. Rutherford's investigation of thorium led to his 1899 discovery that a gas was emitted from solid thorium which in turn decayed and left behind a solid radioactive deposit.
5. Also in 1899 DeBierne discovers another radioactive element actinium from the discard of the Curies.

¹ P.G. Cook and A.L. Herczeg (1999) Environmental tracers in subsurface hydrology. Kluwer, Netherlands.

² W.F. Giaque and H.L. Johnston (1929) An isotope of oxygen, mass 18, J. Am. Chem. Soc. 51, 1436.

³ H.C. Urey, F.G. Brickwedde and G.M. Murphy (1932 a) A hydrogen isotope of mass 2, Phy. Rev. 39, 1645.

⁴ (1932 b) Hydrogen mass 2 and its concentration, Phy. Rev. 40, 145.

THE FOUR NATURAL DECAY SERIES

6. In 1900 while investigating the radiochemical properties of uranium, W. Crookes and Becquerel made an important discovery: Precipitating a carbonate salt from a solution containing uranium, they discovered that while the uranium remained in the supernatant as a soluble uranyl carbonate complex, the radioactivity originally associated with the uranium was now present in the precipitate, which contained no uranium. Moreover, the radioactivity of the precipitate slowly decreased with time, while the supernatant showed a growth of radioactivity. Similar results were obtained by E. Rutherford and F. Soddy when investigating the radioactivity of thorium.
7. From the discovery mentioned above Rutherford revives in 1902 the concept of transmutation.
8. In 1905 Otto Hahn found an important intermediary “radiothorium” came from a radium-bearing ore. There was speculation at this point that there might be a “mixing” of both the radium and thorium series.
9. In 1907 Bertram Boltwood was positive that Hahn was incorrect. He demonstrated that ionium linked the radium and uranium decay chains.
10. Hahn again pointed out overlapping of the thorium and uranium chains at mesothorium, but Fajans showed in 1913 that this was really isotopy. While investigating beta decay he found still another new element, UX_2 . In 1918 Hahn discovered an isotope of UX_2 , proto-actinium; by 1921 he showed that UZ was an isomer of UX_2 (the first isomer). Isotopy explained the overlapping of chemical names, and proto-actinium (later shortened to protactinium) was the parent of the third natural decay chain.
11. In 1923 A.S. Russell (the only chemist to have worked with both Rutherford and Soddy), wondered: *if the alpha has a mass of 4, with $4n+0$, $4n+2$, and $4n+3$ decay chains, then there must be a $4n+1$ decay chain?* During the next 10 years high-energy alpha particles were used to disintegrate atoms. In 1934 alpha particles from polonium, (first discovered by the Curies), were used by a second generation, the Joliot-Curies, to produce the first artificial radionuclides. Fermi then used alpha particles from the historically second decay chain, radium, to make neutrons to bombard uranium, (which was also historically the first natural decay chain). Following this lead, in the 1940's the Berkeley group of chemists used neutrons to transmute uranium and discover neptunium which was the parent of the missing fourth natural decay series (the $4n+1$ series). Of course, neptunium was not “natural” but is indeed an extinct series.

THE FOUR NATURAL DECAY SERIES

