

## k4 Radioactive and stable Isotopes

< isotope means same place in the Periodic Table >

There is a story about a young mathematics instructor who asked an older professor ‘What do you say when students ask about the practical applications of some mathematical topic?’ The experienced professor said ‘I tell them!’

—Mary L. Boas *Mathematical Methods in the Physical Sciences*, 1966.<sup>2</sup>



The number of neutrons in a nuclide (an isotope’s nucleus) determines its isotopic (stable or radioactive) nature. The name *isotope* was coined by **Frederick Soddy** (1877-1956) in 1913.<sup>3</sup> He and Ernest Rutherford had discovered that radioactive isotopes decay by various modes (**Footnote k4.1**) to become one (or several) isotope(s) of lower atomic number, or mass.<sup>4</sup> Isotopes that are stable do not decay radioactively. For example, the hydrogen isotopes are: stable-ordinary Hydrogen,  ${}^1_1\text{H}$ ; stable Deuterium,  ${}^2_1\text{H}$  (historically the first isotope isolated—by Harold Urey in 1931); and, radioactive Tritium,  ${}^3_1\text{H}$ , that beta-decays to stable Helium-3,  ${}^3_2\text{He}$ .<sup>5</sup>

In describing radioactive decay, the radioactive isotope that decays is called the *parent*, and the isotope(s) that it changes into is called its *daughter* isotope(s). True of many is that decay of *one* parent isotope atom is *one* non-radioactive daughter isotope atom as the *end product* (even though, for some, a variety of radioactive daughter isotopes come between).

The duration (length) of time it takes for a single parent isotope to change to a daughter isotope is unknowable in the same way that whether a flipped coin will come down heads or tails is unknowable. What can be known is the rate of decay of a population of parent isotopes at any moment. In spite of Einstein’s famous contrary desire, nature as modeled here does “play with dice” and as H. C. von Baeyer in *Information*, 2004, reminds, “seems” reliably to play fair. Given an amount of a radioactive matter, the number  $N$  of its radioactive isotopes atoms at that time  $t$  is determined. What is then observed is that the proportion of these that decay  $-\Delta N/N$  in a unit of time  $\Delta t$  is a constant:

$$\frac{-\Delta N/N}{\Delta t} = \text{constant}.$$

At any moment, ideally and for simplicity (although Newton long ago warned in the ‘Account’ to the *Commercium Epistolicum* (1715) that a finite velocity  $\dot{x}$  cannot sensibly be taken for an infinitesimal  $dx$ ) we assume <sup>6</sup> the process to be described by

$$\frac{-dN/N}{dt} = \lambda.$$

The decay constant  $\lambda$  has been found to be unique for each radioactive isotope. Some parent isotopes change directly, others change via a succession of radioactive daughter isotopes and reaction paths, to a stable daughter isotope(s). The change, called a *nuclear decay reaction*, unlike ordinary chemical reactions, is unaffected by temperature, pressure, or concentration (supercritical masses for neptunium-237, uranium-235, and plutonium-239 are 60, 50, and 10 kg respectively, for example) throughout the range that these environmental variables have, and have had, naturally on, and within, Earth.<sup>7</sup>  $\square$

Examples of  
radioactive parent  
and end stable (non-  
radioactive) daughter  
isotope pairs are:

