

Nuclear Stability

We can establish a pattern of reactions between protons and neutrons in nuclear reactions



The question is why, for example, some nuclei undergo an alpha decay and not a beta decay. This has to do with the **neutrons to protons ratio** (n/p) in the nuclei. When the nuclei of all 1000 known isotopes are plotted based on their number of protons and neutrons, a **band (belt) of stability** is obtained (blue region). The nuclei in this region are stable. The isotopes that fall outside of this region (are off-balance) are radioactive and decay spontaneously. Example B1 is the last element on the band of stability, so all nuclei with 84 or more protons are radioactive. The type of radioactivity depends on the n/p

- The nuclei above the band of stability tend to decrease the n/p ratio.
- The nuclei below the band of stability tend to increase the n/p ratio.



Nuclei with the **magic numbers** of 2, 8, 10, 20, 28, 50, or 82 protons or 2, 8, 20, 28, 50, 82, or 126 neutrons, and in general, with even numbers of protons, neutrons are more stable.

Rates of Radioactive Decay

Radioactive decay obeys first-order kinetics laws. And although the half-life of radioactive elements may vary enormously (10^2 second to billions of years), it is independent of the quantity of the element. This advantage is used in **radiocarbon dating** which is used for **estimating the ages of fossils and artifacts**. The technique is based on the rate of ${}^{14}\text{C}$ decay which spreads from the atmosphere to living organisms.



The half-life of carbon-14 decay is averaged by emission of a β^- particle is 5715 years.



The ${}^{14}\text{C} : {}^{12}\text{C}$ ratio is constant in living organisms. However, when a living organism dies, the ${}^{14}\text{C} : {}^{12}\text{C}$ ratio begins to decrease, and so does the decay rate of ${}^{14}\text{C}$. The relationship of the quantity or rates of decay is given by the first-order rate law:

$$\ln \left(\frac{N}{N_0} \right) = -kt \quad \ln \left(\frac{\text{rate}_t}{\text{rate}_0} \right) = -kt$$

Example: A sample of wood from an Egyptian mummy case gives a count of 9.4 counts/g this is the current decay rate determined experimentally. How old is the wood if its initial decay rate is 15.3 counts/g?

Solution: We are going to use the integrated rate law of first-order reactions. The rates are given, so we need to determine the rate constant of the decay.

The half-life of first-order reactions is $t_{1/2} = 0.693/k$. Therefore, k is:

$$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{5715 \text{ y}} = 1.210 \times 10^{-4} \text{ y}^{-1}$$

$$\ln \left(\frac{9.4}{15.3} \right) = (1.210 \times 10^{-4}) \times t \quad \Rightarrow \quad t = \frac{\ln \left(\frac{9.4}{15.3} \right)}{(1.210 \times 10^{-4})} = \boxed{4,829 \text{ years}}$$

Energy Changes in Nuclear Reactions

The energies involved with nuclear reactions are extremely large. For example, the energy change in this reaction is $-4.1 \times 10^{12} \text{ J/mol}$



For comparison, the energy change for combustion of 1 mol CH_4 is 890 kJ/mol.

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Martha Mackin



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