

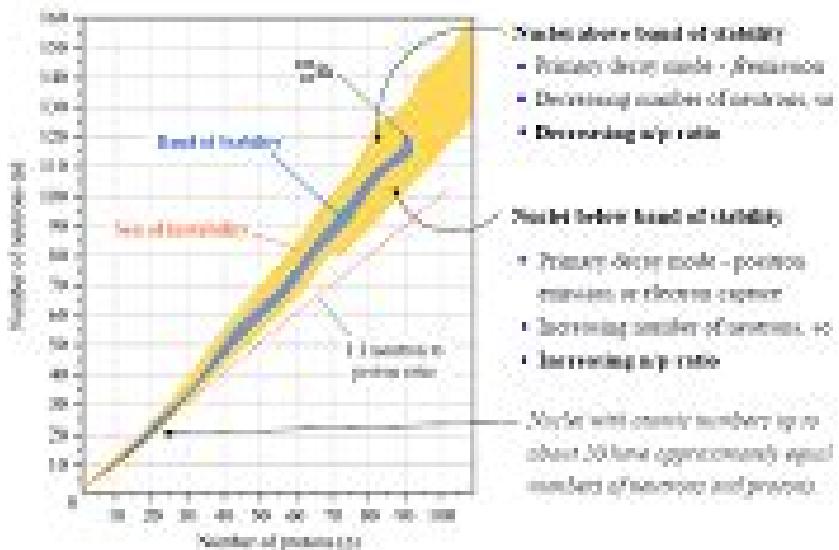
## Nuclear Stability

We can consider a pattern of relationships between protons and neutrons in nuclear reactions.

Number of protons	Number of neutrons	Process	Equation
1	0	Alpha decay	${}^{40}_{19}\text{F} \rightarrow {}^{36}_{18}\text{Ar} + {}^4_2\text{He}$
	1	Electron capture	${}^{40}_{18}\text{Ar} + {}^1_0\text{e} \rightarrow {}^{39}_{17}\text{Cl}$
	2	Positron emission	${}^{40}_{18}\text{Ar} \rightarrow {}^{40}_{17}\text{Cl} + {}^0_1\text{e}$
2	2	Beta decay	${}^{38}_{18}\text{Ar} \rightarrow {}^{38}_{19}\text{K} + {}^0_1\text{e}$
	3		${}^{38}_{19}\text{K} \rightarrow {}^{38}_{20}\text{Ca} + {}^0_1\text{e}$

The question is this: For example, some nuclei undergo an alpha decay and not a beta decay. This has to do with the neutron to proton ratio ( $\text{N}/\text{p}$ ) in the nuclei. When the number of all known known isotopes are plotted based on their number of protons and neutrons, a band of stability of stability is obtained (blue region). The nuclei in this region are stable. The isotopes that fall outside of this region (out of stability) are radioactive and decay spontaneously. Strontium-87 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  $\text{N}/\text{p}$ :

- The nuclei above the band of stability tend to decrease the  $\text{N}/\text{p}$  ratio.
- The nuclei below the band of stability tend to increase the  $\text{N}/\text{p}$  ratio.



Nuclei with the magic numbers of 2, 8, 20, 28, 50, or 82 consist of 1, 8, 20, 28, 50, 82, or 136 neutrons, and as stated, with even numbers of protons, neutrons are more stable.

## Rates of Radioactive Decay

Radioactive decay shows first-order kinetics. And although the half-life of radioactive elements may vary enormously (7.1 second vs. billions of years), it is independent of the quantity of the element. This advantage is used in radiometric dating which is used for estimating the ages of fossils and artifacts. The technique is based on the use of  ${}^{14}\text{C}$  decay which spreads from the atmosphere to living organisms.



The half-life of carbon-14 decay is approximately emission of a  $\beta^-$  particle is 5710 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 rate of decay is given by the first-order rate law:

$$\ln \left[ \frac{N_t}{N_0} \right] = -kt \quad \ln \frac{N(t)}{N_0} = -kt$$

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

Relation: We are going to use the integrated rate law of first-order reactions. The rate,  $-\text{d}N/\text{dt}$ , is proportional to the current count of the decay.

The half-life of first-order reactions is  $t_{1/2} = 0.693/k$ . Therefore,  $k = 2.27 \times 10^{-4} \text{ s}^{-1}$ .

$$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{5710} = 1.209 \times 10^{-4} \text{ s}^{-1}$$

$$\ln \left( \frac{9.4}{15.3} \right) = (1.209 \times 10^{-4}) \times t \quad \ln \left( \frac{9.4}{15.3} \right) = \frac{1.209 \times 10^{-4}}{(1.209 \times 10^{-4})} \times t \quad 1.109 \text{ years}$$

## Energy Changes in Nuclear Reactions

The energy associated with nuclear reactions are extremely large. For example, the energy change in the creation of  ${}^{40}\text{Ca}$  is  $-4.1 \times 10^{24} \text{ J/mol}$ .



For comparison, the energy change for combustion of 1 mol C<sub>6</sub>H<sub>6</sub> is 400 kJ/mol.

# Study Guide Nuclear Chemistry

**Denise Guinn, Rebecca Brewer, Rachel  
C. Lum**

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