

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 proton 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 11 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, 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 decaying to nitrogen 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:

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

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

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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Arturo Cuomo



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Table of Contents Section 2nuclear Chemistry Study Guide Key

1. Understanding the eBook Section 2nuclear Chemistry Study Guide Key
 - The Rise of Digital Reading Section 2nuclear Chemistry Study Guide Key
 - Advantages of eBooks Over Traditional Books
2. Identifying Section 2nuclear Chemistry Study Guide Key
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Section 2nuclear Chemistry Study Guide Key
 - User-Friendly Interface
4. Exploring eBook Recommendations from Section 2nuclear Chemistry Study Guide Key
 - Personalized Recommendations
 - Section 2nuclear Chemistry Study Guide Key User Reviews and Ratings
 - Section 2nuclear Chemistry Study Guide Key and Bestseller Lists
5. Accessing Section 2nuclear Chemistry Study Guide Key Free and Paid eBooks
 - Section 2nuclear Chemistry Study Guide Key Public Domain eBooks
 - Section 2nuclear Chemistry Study Guide Key eBook Subscription Services
 - Section 2nuclear Chemistry Study Guide Key Budget-Friendly Options

6. Navigating Section 2nuclear Chemistry Study Guide Key eBook Formats
 - ePub, PDF, MOBI, and More
 - Section 2nuclear Chemistry Study Guide Key Compatibility with Devices
 - Section 2nuclear Chemistry Study Guide Key Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Section 2nuclear Chemistry Study Guide Key
 - Highlighting and Note-Taking Section 2nuclear Chemistry Study Guide Key
 - Interactive Elements Section 2nuclear Chemistry Study Guide Key
8. Staying Engaged with Section 2nuclear Chemistry Study Guide Key
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Section 2nuclear Chemistry Study Guide Key
9. Balancing eBooks and Physical Books Section 2nuclear Chemistry Study Guide Key
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Section 2nuclear Chemistry Study Guide Key
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Section 2nuclear Chemistry Study Guide Key
 - Setting Reading Goals Section 2nuclear Chemistry Study Guide Key
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Section 2nuclear Chemistry Study Guide Key
 - Fact-Checking eBook Content of Section 2nuclear Chemistry Study Guide Key
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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