

Radioactive Decay

Syll. Statements 13.2.4-13.2.8

Reminder: the evidence for the existence of nuclear energy levels

- Evidence for electrons' energy levels includes the observation that specific wavelengths of visible light are emitted when electrons fall from an excited state to a ground state
- Similarly, when nuclei are in an excited state, gamma rays are emitted in order to bring them back to the ground state.
 - Nuclei can become excited after having gone through natural radioactive decay, or through bombardment with a neutron

12.2.3: Describe the evidence for the existence of nuclear energy levels

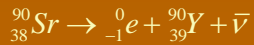
- Gamma rays = high energy photons
- Gamma rays have a discrete amount of energy that is unique to the nucleus from which it is emitted
- Because of this, it can be seen that nuclei have allowed energy levels, just like electrons.

Nuclear Stability

- Smaller atoms: nucleus has approximately the same number of neutrons and protons = stable nucleus
- Heavier nuclei: stability requires more neutrons than protons
 - Every element has a small range of possible numbers of neutrons that will allow the nucleus to remain stable.
 - Deviating from this range results in an unstable nucleus—either too many or too few neutrons.

Nuclear Stability

- Too many neutrons?
 - Most obvious solution is to reduce the number of neutrons, while concurrently increasing the number of protons
 - When a neutron “converts” to a proton, an electron is emitted from the nucleus: Beta-minus decay
 - For example:



Existence of Neutrinos...

- During beta-minus decay, an electron (beta particle) AND an antineutrino are emitted from the nucleus
- During beta-plus decay, a positron (anti-electron) AND a neutrino are emitted from the nucleus
- Laws of conservation of momentum and conservation of energy must be obeyed, even in nuclear decay
- The neutrino (or antineutrino) are essentially massless and are neutral...

Existence of Neutrinos...

- When beta decay was first studied, it was observed that an emitted beta particle had much less kinetic energy than scientists expected...
- The emitting nucleus and the beta particle did not appear to follow the laws of conservation of linear and angular momentum...
- The neutrino was postulated by Wolfgang Pauli in order to account for the missing energy and to ensure that conservation laws were being obeyed

Existence of Neutrinos...

- Wolfgang Pauli called this new particle a "neutrino", which means "little neutral one"
- The neutrino was assumed to be responsible for carrying the extra energy that was otherwise missing, and for carrying the missing angular and linear momentum
- Was not detected for over 25 years—in 1956, neutrinos were first detected in nuclear reactors.

Nuclear stability...again

- Too FEW neutrons?
 - Option 1: A proton converts into a neutron
 - When this occurs, a **positron** is emitted from the nucleus (a positively charged electron), along with a neutrino.



Nuclear stability...again

- Too FEW neutrons?
 - Option 2: Electron Capture
 - An electron from the lowest orbital is drawn into the nucleus, merges with a proton and creates a neutron
 - Other electrons must move from higher energy levels to fill the spot of the now missing electron, causing an emission of X-rays (also results in the emission of a neutrino)



Alpha Decay

- Results in an overall reduction in the mass of a nucleus (by 2 protons and 2 neutrons)
- Brings larger nuclei closer to stability by making it smaller.

Radioactive Decay Law

- Remember: during one half-life, a nucleus will have a 50% chance of decaying
- The rate of decay will depend on the number of unstable nuclei present in the sample
- **Decay Constant (λ):** the ratio between the number of nuclei decaying per unit time and the total number of nuclei for the original isotope sample

$$\frac{\left(\frac{\Delta N}{\Delta t}\right)}{N} = \lambda$$

Radioactive Decay Law

- “Activity” refers to the rate of decay for a particular sample, and can be expressed with the equation:

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

- The equation is negative, implying that the rate of decay will decrease as the number of nuclei in the sample decreases

Radioactive Decay Law

- The previous equation can be rewritten (after applying some calculus, that we’re not going to worry about right now):

$$N = N_0 e^{-\lambda t}$$

- N = remaining activity; N_0 = original activity; t = time
- Units for activity: Becquerel
1 Bq = 1 event per second

Half-life and Decay Constant

- When one half-life has passed, the total activity of a radioactive sample has decreased by one-half:

$$\text{At } t = t_{1/2}, N = \frac{1}{2}(N_0)$$

And our expression becomes:

$$\frac{1}{2} = e^{-\lambda t_{1/2}}$$

OR

$$2 = e^{\lambda t_{1/2}}$$
