Pre-Health Post-Baccalaureate Program Study Guide and Practice Problems

Course: CHM2046

Textbook Chapter: 24 (Silberberg 6e)

Topics Covered: Introduction to Nuclear Chemistry

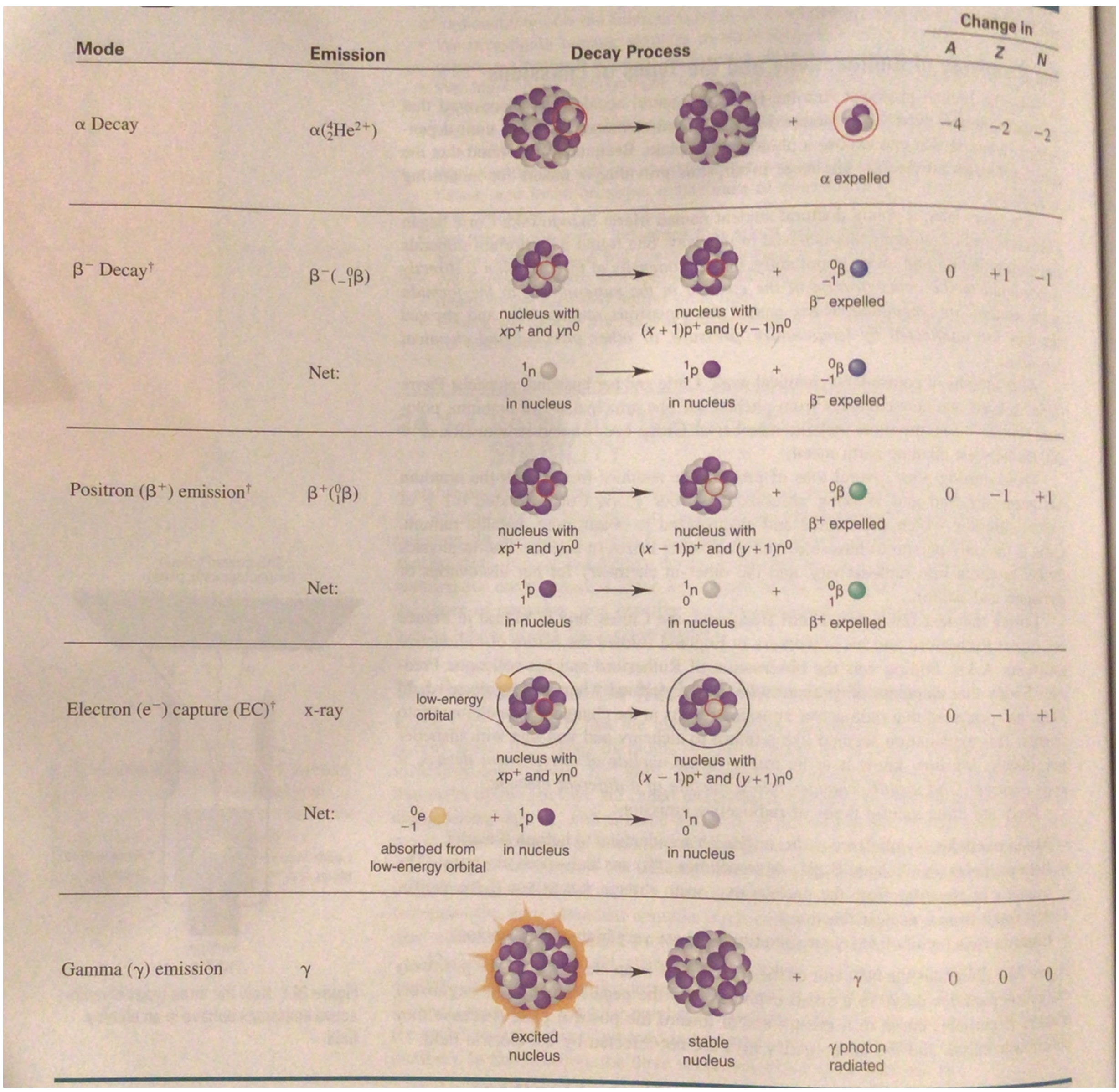
Note: Read this chapter in the textbook for background into nuclear theory and historical developments in the field of nuclear chemistry. I did not include that into this study guide, instead choosing to exclusively focus on the science.

Created by Isaac Loy

1. The Nucleus and Decay

A nucleus is the densest part of the atom and contains nearly all of an atom's mass. A nucleus is made of nucleons (protons and neutrons fall under this broader category).

The nucleus of a stable atom will remain "as is" indefinitely, but the vast majority of nuclei are unstable - that is, they are radioactive. Radioactive atoms are those which decay and emit nucleons. Therefore, decay causes an atom of one element to turn into a different element. When an atom decays, it emits not only nucleons, but also energy.



Alpha decay: An alpha particle (Helium-4 nucleus) is emitted from the parent nucleus. After emission, the nucleus has two fewer protons and two fewer neutrons (A decreases by 4, Z decreases by 2).

Beta- decay: A neutron is converted into a proton and a Beta- particle is emitted. After emission, the nucleus has one additional proton and one fewer neutron (A does not change, Z increases by 1).

Beta+ decay: A proton is converted into a neutron and Beta+ particle is emitted. After emission, the nucleus has one fewer proton and one additional neutron (A does not change, Z decreases by 1).

Electron capture: A low-energy electron "neutralizes" a proton, thus converting it into a neutron. After capture, the nucleus has one fewer proton and one additional neutron (A does not change, Z decreases by 1).

Gamma emission: An excited (high energy) nucleus emits a gamma ray and reaches a more stable (lower energy) level. After emission, the number of protons and neutrons have not changed.

How can we predict which mode of decay a certain nucleus will undergo? We can examine its make-up and make educated guesses.

If the mass number is close to the atomic mass, the nucleus is stable.

If the mass number is much higher than the atomic mass, then the unstable nucleus has a large number of neutrons and will likely undergo Beta- emission to rid itself of those neutrons.

If the mass number is much lower than the atomic mass, then the unstable nucleus has a large number of protons and will likely undergo Beta+ emission or electron capture to increase the number of neutrons.

2. Half-Life

Half-life should be a familiar term - in this case, it describes the amount of time required for half of the starting material (in terms of mass, number of nuclei, or activity) to radioactively decay.

The equation for radioactive half-life is:

$$t_{1/2} = \frac{\ln 2}{k}$$

Where k is the decay constant and is specific to each nuclide.

3. Transmutation

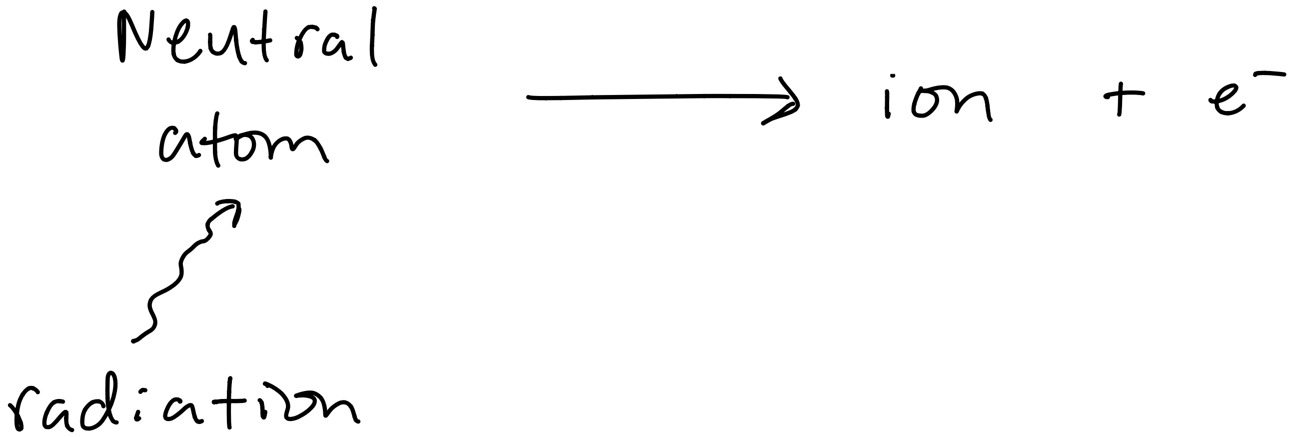
Transmutation is the process by which an atom of one element is converted into an atom of another element. This happens when an alpha particle interacts with an atom in elemental form. Think about this as a reaction, of sorts.

Rutherford accomplished this for the first time when he produced Oxygen-17 and a proton from Nitrogen and an alpha particle:

$$^{14}_{7}N + ^{4}_{2}\alpha \rightarrow ^{1}_{1}p + ^{17}_{8}O$$

4. Ionizing Radiation

When radiation hits an atom, it can dislodge electrons. This causes the formation of an ion and a free electron:



The textbook makes an important point: although decay, by itself, involves processes that happen to and in the nucleus, its downstream effects can involve the freeing of electrons.

5. You've been waiting your whole life to use this equation

The most famous application of nuclear chemistry is Einstein's mass-energy equivalence.

Recall that both mass and energy can neither be created nor destroyed. Combining both of these laws, we can be confident that the total mass-energy of the universe remains constant across time.

Einstein suggested the following:

$$\Delta E = \Delta m c^2$$

Where Δm is the mass of the products - mass of the reactants.

This equation gives us the amount of energy required (absorbed or released) to break apart any nucleus into nucleons.

6. Review + Fission and Fusion

See the below video, which does a nice job of clearly explaining the science covered in this chapter. This material is difficult to understand because it is quite theoretical, and having a visual may be helpful.

https://youtu.be/fES21E0qebw

Problems

T/F: Nuclear Fission involves isotopes of hydrogen.

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Fusion, <u>NOT</u> fission, involves the combining of Hydrogen-2 and Hydrogen-3 to produce energy.

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Mass of 1 proton ≈ mass of 1 neutron ≈ 1.008 amu

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$$^{12}C \rightarrow 6\,^{1}_{1}p + 6\,^{1}_{0}n$$

$$\Delta E = \Delta m c^2$$

$$\Delta E = (m_p - m_r) c^2$$

$$\Delta E = [(12 \times 1.008) - 12] c^2$$

$$\Delta E = (12.096 - 12) c^2$$

$$\Delta E = \left(9.60 \times 10^{-5} \frac{kg}{mol}\right)\left(3 \times 10^{8} \frac{m}{s}\right)^2$$

$$\Delta E \approx 8.9 \frac{kJ}{mol}$$

Old mammal bones were found in a cave. A sample of the bones shows that the specific activity of the bones is 5.22 d/min•g. How old are the bones, if the Carbon-12/Carbon-14 ratio for living organisms result in a specific activity of 15.3 d/min•g, and the half life of Carbon-14 is 5730 years?

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$$K = \frac{\ln 2}{t_{1/2}}$$

$$K = \frac{0.693}{5730\ yr}$$

$$K = 1.21 \times 10^{-4}\ yr^{-1}$$

$$t = \frac{1}{K} \ln \frac{A_0}{A_t}$$

$$t = \frac{1}{1.21 \times 10^{-4}} \cdot \ln\left(\frac{15.3}{5.22}\right)$$

$$t = 8.89 \times 10^{3}\ yr$$

$$t \approx 8900\ \text{years}$$