

Nuclear Chemistry

The properties of the nucleus are not of primary importance to chemists. For the most part, the nucleus can be regarded as a collection of nucleons (neutrons and protons). The number of protons in a particular nucleus is called the atomic number (Z) and the sum of neutrons and protons is the mass number (A). Atoms that have identical atomic numbers but different mass number values are called isotopes. The term nuclide is a unique atom, represented by the symbol: ${}^A_Z X$.

Types of Radioactive Decay

- Some important observations about radioactive decay.
 - All nuclides with 84 or more protons are unstable with respect to radioactive decay.
 - **Light nuclide are stable when Z equals (A - Z), that is when the neutron/proton ratio is 1.**
 - In all cases of nuclear decay the mass number and atomic number both conserve mass.
- An alpha particle or **α particle** is a helium nucleus. (${}^4_2\text{He}$). **Alpha particle production is a very common mode of decay for heavy radioactive nuclides.**
 - Alpha particles have a mass of 4 amu, are positively charged and are the most easily stopped of the three particles (a sheet of paper will stop them). It is the least dangerous.
 - Uranium-238 decays by alpha particle production: ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\text{He}$
- Beta particle or **β -particle** production is the most common decay process in which the mass number of the decaying nucleus remains constant.
 - Beta particles are high speed electrons, with a mass of 0.00055 amu, a negative charge and can be stopped by a sheet of aluminum. They are more penetrating and more dangerous than alpha particles.
 - Thorium-234 decomposes by losing a beta particle: ${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^0_{-1}\text{e}$
 - The beta particle is assigned the mass number 0, since its mass is tiny compared with that of a proton or neutron.
 - **Beta particle production changes neutrons into protons.**
- A **gamma ray**, or **γ ray**, refers to a high energy photon.
 - Gamma rays have no mass or charge, and are the most penetrating (several cm's of lead are needed to stop them). They can cause severe damage.
 - Frequently, gamma ray production accompanies nuclear decays, such as in the alpha particle decay of uranium-238: ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\text{He} + 2^0_0\gamma$
 - The emission of gamma rays is one way a nucleus with excess energy (in an excited nuclear state) can relax to its ground state. You will not be expected to predict gamma ray production.
- **Positron production occurs for nuclides whose neutron/proton ratios are too small).**
 - The positron is a particle with the same mass as the electron but opposite charge.
 - Positron production occurs in sodium-22: ${}^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + {}^0_1\text{e}$
 - **In positron production a proton is changed to a neutron.**
 - The positron is the antiparticle of the electron.

Summary:

Type of Decay	Example	Why?
Alpha	${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^4_2\text{He}$	Occurs in heavier nuclides.
Beta	${}^{227}_{89}\text{Ac} \rightarrow {}^{227}_{90}\text{Th} + {}^0_{-1}\text{e}$	The most common nuclear decay. A neutron changes to a proton.
Gamma	Excited nucleus \rightarrow Ground State Nucleus + ${}^0_0\gamma$	To release excess energy. Accompanies other types of decay
Positron Production	${}^{13}_7\text{N} \rightarrow {}^{13}_6\text{C} + {}^0_1\text{e}$	Occurs when n/p ⁺ ratio is less than 1. A proton becomes a neutron.

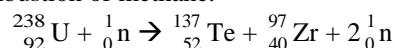
- Another method, using a mass spectrometer, allows for a very accurate determination of the $^{14}_6\text{C}/^{12}_6\text{C}$ ratio and only requires about 10^{-3} g.

Nuclear Fission and Nuclear Fusion

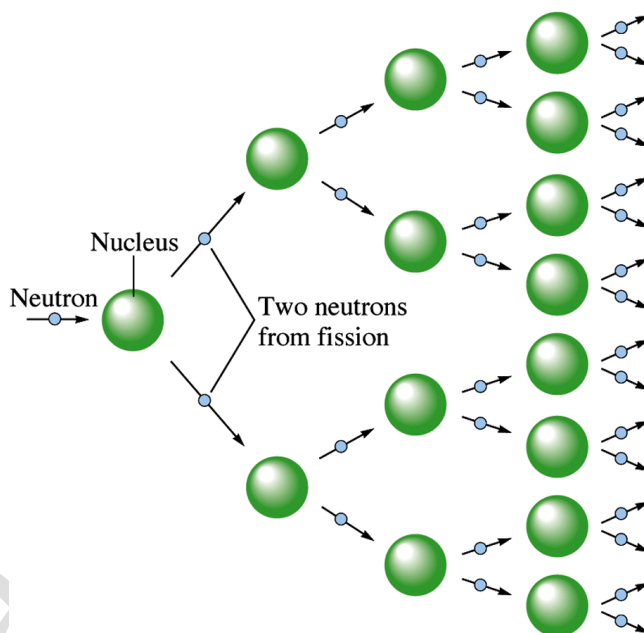
- Combining of two light nuclei to form a heavier, more stable nucleus is called **fusion**.
- Splitting a heavy nucleus into two nuclei with smaller mass numbers is called **fission**.
- Because of the bonding energies involved in holding the nucleus together, both these processes involve energy changes more than a million times larger than those associated with chemical reactions.

Nuclear Fission

- The fission of $^{238}_{92}\text{U}$ produces about 26 million times more energy than the combustion of methane.



- In addition to the product nuclides, neutrons are also produced in the fission reactions of $^{238}_{92}\text{U}$. This makes it possible to have a self-sustaining fission process - a **chain reaction**.
- For the fission process to be self-sustaining, at least one neutron from each fission event must go on to split another nucleus.
- If on average, **less than one** neutron causes another fission event, the process dies out and the reaction is said to be **subcritical**.
- If **exactly one** neutron from each fission event causes another fission event, the process sustains itself at the same level and is said to be **critical**.
- If **more than one** neutron from each fission event causes another fission event, the process rapidly escalates and the heat buildup causes a violent explosion. This situation is described as **supercritical**.
- To achieve the critical state, a certain mass of fissionable material, called the **critical mass**, is needed.



Homework:

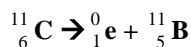
1. Define nucleon.
neutrons and protons
2. What is an alpha particle?
 α particle is a helium nucleus. (^4_2He)
3. Which nuclides usually experience alpha decay?
Alpha particle production is a very common mode of decay for heavy radioactive nuclides.
4. What is a beta particle?
Beta particles are high speed electrons.
5. What transformation happens in beta particle production?
Beta particle production changes neutrons into protons.
6. What is a gamma ray?
A gamma ray, or γ ray, refers to a high energy photon.

7. What transformation occurs in positron production?

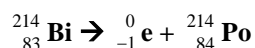
In positron production a proton is changed to a neutron.

8. Write balanced equations for each of the following processes.

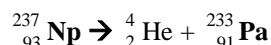
- ${}_{6}^{11}\text{C}$ produces a positron



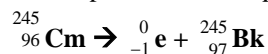
- ${}_{83}^{214}\text{Bi}$ produces a beta particle



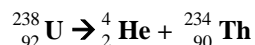
- ${}_{93}^{237}\text{Np}$ produces an alpha particle



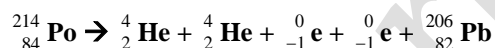
- ${}_{96}^{245}\text{Cm}$ produces a beta particle



- ${}_{92}^{238}\text{U}$ produces an alpha particle



- ${}_{84}^{214}\text{Po}$ produces two alpha particles and two beta particles.



- ${}_{98}^{251}\text{Cf} \rightarrow 2 {}_{0}^{1}\text{n} + {}_{54}^{131}\text{Xe} + {}_{44}^{118}\text{Ru}$ (fill in the missing information)

- ${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + {}_{-1}^{0}\text{e}$ (fill in the missing information)

- ${}_{92}^{235}\text{U} + {}_{0}^{1}\text{n} \rightarrow {}_{55}^{141}\text{Cs} + 3 {}_{0}^{1}\text{n} + {}_{37}^{92}\text{Rb}$ (fill in the missing information)

9. Radioactive iodine-131 has a half-life of eight days. The amount of a 200.0 gram sample left after 32 days would be:

12.50 grams

10. Iodine-131 is a radioactive isotope with a half-life of 8 days. How many grams of a 64 g sample of iodine-131 will remain at the end of 24 days?

8.0 grams

11. Actinium-225 has a $\frac{1}{2}$ life of 10 days. How many grams of a 2.00 gram sample will remain at the end of 60 days?

0.0313 grams

12. The half-life of ${}^{55}\text{Cr}$ is about 2.0 hours. The delivery of a sample of this isotope from the reactor to a certain laboratory requires 12 hours. About what mass of such material should be shipped in order that 1.0 mg of ${}^{55}\text{Cr}$ is delivered to the laboratory?

64 milligrams

13. Silver-111 has a half-life of 7.45 days. If you have 400.0 grams now, how much will remain after 30.0 days?
24.54 grams

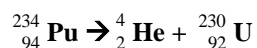
14. Sodium-24 has a half-life of 15.00 hours. If you have 32.40 grams now, how much will remain after 5.00 hours?
25.72 grams

15. Tungsten-181 has a half-life of 121.2 days. If you have 2013 grams now, how much will remain after 365 days?
249.6 grams

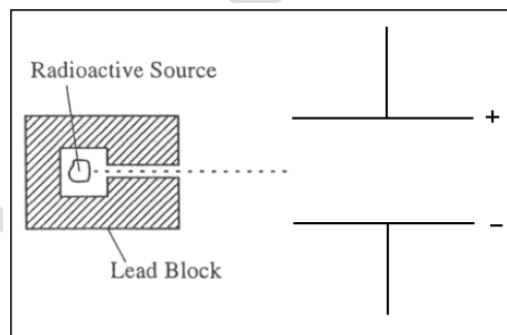
16. Strontium-90 has a half-life of 29.12 years. If you have 2.00 micrograms now, how much will remain after 83.16 years?
0.276 micrograms

17. Answer each of the following questions regarding radioactivity.

(a) Write the nuclear equation for decay of Plutonium-234 by alpha emission.



(b) Describe how alpha, beta, and gamma rays each behave when they pass through an electric field. Use the diagram below to illustrate your answer.



(c) Why is it not possible to eliminate the hazard of nuclear waste by the process of incineration?