

CHAPTER 23 NUCLEAR CHEMISTRY

23.1 THE NATURE OF NUCLEAR REACTIONS

radioactivity - the spontaneous decay of an unstable nucleus with accompanying emission of radiation.

nuclide - atom with a specific number of protons and neutrons in its nucleus.

⇒ There are 271 stable nuclides in nature, others are radioactive

radionuclide - unstable isotope that undergoes nuclear decay

⇒ All isotopes of elements with ≥ 84 protons are radioactive; specific isotopes of lighter elements are also radioactive. (E.g. ${}^3_1\text{H}$)

nucleons = # protons + # neutrons

Nuclear reactions differ from ordinary chemical reactions

- Atomic numbers of nuclei may change (elements are converted to other elements or an element can be converted to an isotope of that element).
- Protons, neutrons, electrons and other elementary particles may be involved in a nuclear reaction.
- Reactions occur between particles in the nucleus.
- Matter is converted to energy & huge amounts of energy are released.
- Nuclear reactions involve a specific isotope of an element; different isotopes of an element may undergo different nuclear reactions.

Types of Radioactive Decay:

1) alpha, α , emission

α particles - high energy and low speed + charged particles; ${}^4_2\text{He}$ (helium-4)

E.g. emission of an α particle: ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\text{He}$

2) beta, β , emission

β particles – high energy and high speed – charged electrons: ${}^0_{-1}\text{e}$

E.g. emission of a β particle: ${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^0_{-1}\text{e}$

- During β decay, a neutron is converted into a proton: ${}^1_0\text{n} \rightarrow {}^1_1\text{p} + {}^0_{-1}\text{e}$

3) gamma, γ , emission; gamma emission accompanies other types of decay

γ particles - high energy photons, very penetrating: ${}^0_0\gamma$

4) positron, ${}^0_1\text{e}$, emission - same mass, but opposite charge of electron

${}^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + {}^0_1\text{e}$

5) Electron capture - β particle is captured instead of emitted

${}^{82}_{37}\text{Rb} + {}^0_{-1}\text{e} \rightarrow {}^{82}_{36}\text{Kr}$

23.2 NUCLEAR STABILITY

Nuclear Stability

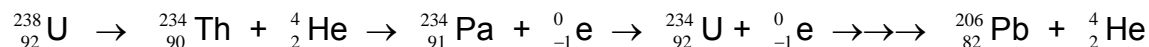
- Nuclei containing 2, 8, 20, 50, 82, or 126 protons or neutrons are generally more stable than nuclei that do not possess these “magic” numbers.
- As the atomic number increases, more neutrons are needed to help bind the nucleus together, so there is a high neutron:proton ratio.
- Nuclei of elements with > 83 protons are unstable due to the large # of nucleons present in the tiny nucleus; by undergoing radioactive decay unstable nuclei can form more stable nuclei.
- Nuclei with both even numbers of both protons & neutrons are generally more stable than those with odd numbers:

# protons	# neutrons	# stable nuclei
even	even	164
even	odd	53
odd	even	50
odd	odd	4

23.3 NATURAL RADIOACTIVITY

Radioactive Decay Series

Many heavy elements undergo several sequential emissions before forming a more stable nuclei:



Kinetics of Radioactive Decay

- Different isotopes decay at different rates; rates vary from ms to days to years.
- Radioactive decay is a first order rate process; all radioactive substances have a characteristic half-life:

$$kt_{1/2} = 0.693$$

$$t_{1/2} = \text{half-life}; k = \text{rate constant}$$

$$\ln \frac{A_t}{A_0} = -kt$$

$$A_0 = \text{initial activity or amount}; A_t = \text{activity after a certain time}$$

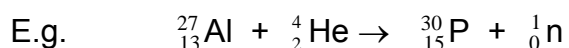
$$\frac{A_t}{A_0} = \text{fraction of material remaining after time } t$$

23.4 NUCLEAR TRANSMUTATION

Transmutation - Change of one element to another as a result of bombardment by high-energy particles (e.g. neutrons, electrons, and other nuclei).

- Rutherford prepared 1st synthetic nuclide, ${}^{17}\text{O}$, in 1919; Irene Curie prepared 1st radioactive nuclide, ${}^{30}\text{P}$, in 1934.
- All trans-Uranium elements ($Z > 92$) are both synthetic (man-made) and radioactive.

Nuclear transmutations can show α -, β -, and γ -emissions as well as production of protons, neutrons, and other isotopes:

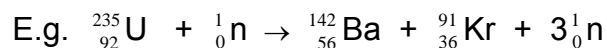


23.5 NUCLEAR FISSION

Fission - A nuclear reaction that releases energy as a result of splitting of large nuclei into smaller ones.

Nuclear Power plants use fission to split U-235 to produce energy:

1. U-235 is bombarded with slow neutrons - this produces smaller nuclei as well as more neutrons and energy.
2. A chain reaction results because each neutron produced can cause fission of another U-235 nucleus.



Critical mass - minimum mass required to sustain a chain reaction.

Control rods are made of B or Cd; these rods absorb neutrons so the process doesn't accelerate too rapidly. Rods are raised/lowered to control the speed of the process.

Fuel rods are made of U-235. ${}^{238}\text{U}$ is the most abundant U isotope but is not fissionable so uranium must be enriched to increase the amount of ${}^{235}\text{U}$.

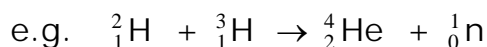
Moderator - slows down the neutrons. Water or other liquid coolant surround rods. The water serves to 1) slow down neutrons so they can collide with U-235; 2) transfer heat to steam generator.

Primary problems with nuclear power plants:

- 1) safety (Chernobyl and Three Mile Island had cooling system failures that led to reactor meltdowns. Chernobyl also did not have containment building around reactor.)
- 2) nuclear waste - some products will remain radioactive for thousands of years.

23.6 NUCLEAR FUSION

Fusion - A nuclear reaction that releases energy as a result of the union of smaller nuclei to form larger ones.



- Fusion generates even more energy than fission and creates little radioactive waste, so it would provide a wonderful source of energy.
- ...but, fusion requires very high temps (tens of millions of degrees Celsius) in order for nuclei to overcome strong repulsive forces – magnetic fusion reactors are being designed and tested.

23.7 APPLICATIONS OF RADIOACTIVE ISOTOPES

- Nuclear power plants
- Medical diagnosis and treatment e.g. PET scan monitors glucose metabolism in brain using C-11 isotope; I-131 measures activity of thyroid
- Carbon dating (measure amount of C-14 remaining in a sample)
- Synthesis of new elements
- Irradiation of food - preserves food & destroys parasites
- Nuclear Weapons (Atomic bombs and H bombs)