Chemistry 500: Chemistry in Modern Living

Topic 5: The Fires of Nuclear Fission

Atomic Structure, Nuclear Fission and Fusion, and Nuclear Weapons

Chemistry in Context, 2nd Edition: Chapter 8, Pages 245-280

Chemistry in Context, 3rd Edition: Chapter 7, Pages 265-304

Outline Notes by Dr. Allen D. Hunter, YSU Department of Chemistry, ©2000.

Outline

5A Atomic and Nuclear Structure

- Atomic Structure:
  - Nucleus
  - Electron Cloud

- Nuclear Structure:
  - Neutrons and Protons
  - Strong Nuclear Force vs. Electrostatic Force
  - Rubber Baggie Model

- Isotopes
  - Atomic Number
    - Determined by number of protons
  - Mass Number
    - Equals the total number of protons and neutrons

- Ask Students: Give the number of protons and the number of neutrons for each of the following isotopes or give the atomic symbol, as required
- Group Activity

$^{1}_{0}n$ $^{1}_{1}P^{+}$ $^{0}_{-1}e$

- 32 protons and 37 neutrons ⇒
- 17 protons and 16 neutrons ⇒

$^{13}_{6}C$

$^{12}_{6}C$

$^{235}_{92}U$

$^{238}_{92}U$

5B Fission and Fusion

- Fission Reactions are nuclear reactions that split the nucleus into smaller fragments

- Fusion Reactions are nuclear reactions that join two units to form a larger nucleus

- These nuclear reactions can be extremely exothermic
  - They produce large amounts of heat
  - For example ^{235}U fission $\Rightarrow$ energy equivalent to 33,000 tons of TNT from 1 kg of Uranium
  - This energy is produced via the conversion of mass to energy
  - Einstein $\Rightarrow$ $E = m c^2$

5C Nuclear Reactions and Chain Reactions

- Involve the splitting or combining of nuclei and fragments
  - They can be balanced much like chemical reactions

$$ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow \left[{}^{236}_{92}U \right] \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n $$

- Chain Reactions
  - Graphics from Text: Figure 8.3 in 2nd Edition and 7.2 in 3rd Edition, Chain Reaction Diagram
    - Average of 2 to 3 neutrons per fission
    - Induced nuclear fission

5D Nuclear Fission Reactors

- Graphics from Text: Figure 7.3 in 3rd Edition, Diagram of a nuclear power plant

- Roles of Major Components
  - Fuel Rods
  - Moderator (Thermal Neutrons)
  - Control Rods
  - Steam system
    - Piping
    - Turbines
    - Cooling towers / heat exchangers

- Graphics from Text: Figure 7.4 in 3rd Edition, Diagram of fuel assembly in nuclear power plant

- Comparison of various reactor types
  - Key variables
    - Level of enrichment
    - Moderator type
    - Cooling fluid
  - Pressurized light water reactor
    - US Navy
  - Heavy water reactor, CANDU
  - Liquid metal cooled reactor
  - Graphite moderated / Helium Cooled reactor
  - Natural Reactors

- What prevents melt downs
  - Active control systems
    - Redundancy
    - Mechanical errors
      - Brittle piping (alloys), Welding, Pumps
    - Human errors
      - Homer Simpson
  - Passive control systems
    - Energy density
    - No-maintenance piles
  - What happened at Chernobyl
- Breeder Reactors

$$ {}^{1}_{0}n + {}^{238}_{92}U \longrightarrow \left[{}^{239}_{92}U \right] \longrightarrow {}^{239}_{94}Pu + 2\ {}^{0}_{-1}e $$

5E Radiation and Radioactive Decay

- Graphics from Text: Table 8.1 in 2nd Edition and 7.1 in 3rd Edition, Radioactive emissions

- Types of Radiation
  - Alpha particles, Helium nuclei
  - Beta particles, electrons
  - Gamma rays, high energy photons
  - Neutrons

- Variations in penetrating power

- Doses
  - Lethal vs. typical
  - The controversy about low doses

- Graphics from Text: Table 8.4 in 2nd Edition and Figure 7.10 in 3rd Edition, US Background Radiation Sources

- Radioactive Decay
  - Half life of an isotope for spontaneous decay
    - Ranges of half lives in common isotopes

  - Graphics from Text: Figure 8.9 in 2nd Edition and 7.12 in 3rd Edition: Radioactive decay curve for ^{239}Pu

5F Nuclear Power and the World

- Graphics from Text: Table 8.5 from 2nd Edition and Table 7.4 from 3rd Edition, Nuclear Power Statistics for Selected Countries

- Graphics from Text: Figure 8.10 from 2nd Edition and Figure 7.19 from 3rd Edition, Percentage of Electrical Power Generated from Nuclear Reactors for Selected Countries

- Ask Students: Develop some reasons why the differences between different countries
  - Group Activity

5G Nuclear Bomb Design

- Critical Mass
  - 15 to 18 kg of ^{235}U

- Crude Fission bomb design
  - Tube cannon
  - Collapsing shell

- Crude Fusion bomb design

- Miniaturization of bombs

Index of Vocabulary and Major Topics