Chapter 22: Nuclear Chemistry

22.1 Reactions and Characterisitcs

- Z – Atomic Number
- A – Mass Number
- Isotopes – same atom, different # of neutrons

  $^{A}_{Z}Symbol$

- Nucleons – nuclear particles
- Nuclide – nucleus of given isotope

22.1 Reactions and Characterisitcs

- Nuclear Reaction – Change nucleus
  - Different from chemical reactions
    - Change in nucleus
    - Different isotopes behave the same in chemical reactions, not in nuclear reactions
    - Rate is unaffected
    - Nuclear reactions same whether in elemental form or compound
    - $\Delta E_{nuclear}$ >>> $\Delta E_{reaction}$

22.2 Nuclear Reactions & Radioactivity

- Radioactive = spontaneous decay or emission of radiation
- Radionuclide – radioactive nucleus
- 3 Major Types
  - Rutherford Studied

22.2 Nuclear Reactions & Radioactivity

- Alpha (α) – Helium Nuclei
  - ($^{4}_{2}He$)
  - Common in Heavy Radioisotopes
  - Example:
    - $^{238}_{92}U$ →
    - Note: Nuclear Rxns MUST be balanced wrt A & Z
      - Also ignore charges

22.2 Nuclear Reactions & Radioactivity

- Beta (β) – Stream of electrons
  - Written as $^{0}_{-1}e$ or β^{-}
    - Use $^{0}_{-1}e$ when writing nuclear rxns
  - Example:

    $^{131}_{53}I$ →

22.2 Nuclear Reactions & Radioactivity

- Gamma (γ) – "packets of energy"
  - What is a "packet of energy"?
  - Does it change the nucleus?
    - Usually accompanies α & β

22.2 Nuclear Reactions & Radioactivity

- Other Types of Radiation: (2)
  - Positron Emission ($^{0}_{1}e$ or β^{+})
    - In nucleus: proton → neutron releasing positive charge
    - Example: $^{40}_{19}K \rightarrow$
  - Electron Capture ($^{0}_{1}e$)
    - Nucleus captures inner-shell electron
      - Proton → Neutron
    - Example: $^{197}_{80}Hg + \quad \rightarrow$

22.2 Nuclear Reactions & Radioactivity

- Summary of Radioactive Decay, see Table 22.1 p 906
- Examples: Write balanced nuclear equations for the following.
  - A) alpha emission of Curium-242
    - $^{242}_{96}Cm \rightarrow$
  - B) Beta emission of magnesium-28
    - $^{28}_{12}Mg \rightarrow$
  - C) Positron emission of Xenon-118
    - $^{118}_{54}Xe \rightarrow$

22.3 Radioactive Decay Rates

- First Order:
  - Decay Rate = k x N
    - k = rate constant
    - N = # of radioactive nuclei
  - IRL –

$$Ln\left(\frac{N_t}{N_o}\right) = -kt$$

22.3 Radioactive Decay Rates

- IRL Cont. (1st Order)
  - Half-life:
    - $N_t = \frac{1}{2} N_o$
  - Then we get:
    - $t_{1/2} = \frac{Ln2}{k}$ or $k = \frac{Ln2}{t_{1/2}}$

Plug $k = \frac{Ln2}{t_{1/2}}$ into IRL to get:

$$Ln\left(\frac{N_t}{N_o}\right) = (-\ln 2)\left(\frac{t}{t_{1/2}}\right)$$

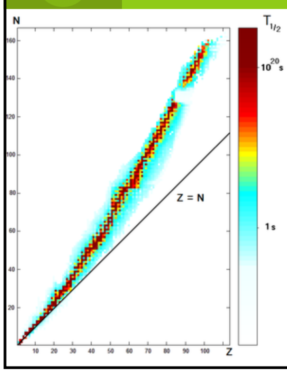
22.3 Radioactive Decay Rates

- Examples:
  - The Decay Constant for ^{24}Na is 4.63×10^{-2} h^{-1}. What is the half-life?
  - The half-life of Radon-222 is 3.823 days. What is the decay constant?
  - ^{32}P has a ½ - life of 14.26 days. What percent of the sample remains after 35 days?
  - What is the ½ - life of ^{59}Fe, if a sample with an initial decay rate of 16,800 disintegrations/min decays at a rate of 10,860 disintegrations/min after 28.0 days?
    - (Hint: Think ratio)

22.4 Nuclear Stability

- Unstable Isotopes – decay too fast to be measured
- Stable – decay can be measured
- Nonradioactive (stable indefinitely) – DO NOT decay at all
- Why are some radioactive and others not?
  - Proton/Neutron Ratio
  - 1st 92 Naturally Occurring
  - Next 17 "Transuranium Elements"

22.4 Nuclear Stability



- "Band of Stability"
- 264/3600 known nuclides are stable indefinitely
- "Island of Stability" – predicted for a few super heavy nuclides
- See Figure 22.3 p.911

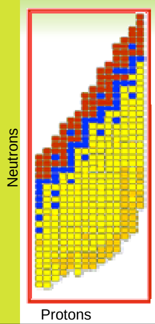
22.4 Nuclear Stability

- Generalizations:
  - Every element has at least 1 radioactive isotope
  - H has only stable isotope with protons > neutrons
    - Lighter than Ca (protons ≈ neutrons or 1 more neutron than protons)
  - Ratio $n^0 : p^+$ gradually increases for elements heavier than Ca
  - All isotopes heavier than ^{209}Bi are radioactive
  - 207/264 indefinitely stable isotopes have even # of n^0

22.4 Nuclear Stability

- Neutrons seem to be "Nuclear Glue"
  - Overcome proton – proton repulsion
  - More protons; more glue
- Magic # of protons or neutrons – 2, 8, 20, 28, 50, 82, 126
  - Shell model proposed

22.4 Nuclear Stability



- What do these processes do to change the neutron/proton ratio?
- Example: Match ^{173}Au, ^{199}Au with alpha or beta emission

22.4 Nuclear Stability

- Decay Series:
  - Many heavy radionuclei have to go through a series of decay processes.
  - Uranium-238 goes through 14 steps

22.5 Energy Changes & Nuclear Reactions

- Cannot directly measure the energy when we combine nucleons to form a nucleus
  - Ex. $2{}_1^1H + 2{}_0^1n \rightarrow {}_2^4He$
    - This happens in the sun! Therefore the E_a is really high!
- Einstein 1905 → $E=\Delta mc^2$
  - Corresponds energy change with mass change in nuclear reaction
  - Mass Defect – difference between the mass of (protons & neutrons) VS the mass of the nucleus
    - Mass of nucleons – mass of nucleus
  - Binding Energy – Energy calculated from Mass Defect

22.5 Energy Changes & Nuclear Reactions

- Example:
  - Helium-6 is a radioactive isotope with $t_{1/2}$ = 0.861 s
    - Calculate the mass defect in (g/mol)
      - Given: Mass of ^{6}He is 6.01889 amu
        - Mass of proton = 1.00728 amu
        - Mass of neutron = 1.00866 amu
        - Mass of electrons = 5.486×10^{-4} amu
    - Calculate the binding energy in MeV/nucleon
      - 1 MeV = 1.60×10^{-13} J

22.5 Energy Changes & Nuclear Reactions

- Mass defect in chemical reactions
  - Example:
    - Calculate the change in mass of the following reaction.
    - $2H \rightarrow H_2 \quad \Delta E = -436\ kJ$
      - Remember: $1J = kg\frac{m^2}{s^2}$

22.6 Nuclear Fission & Fusion

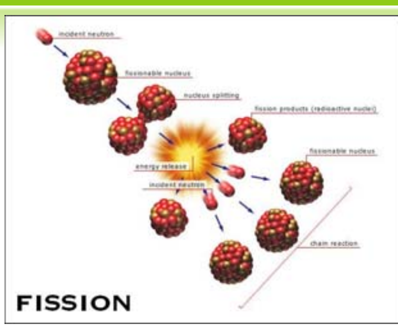
- Binding Energy peaks at $^{56}_{26}Fe$
  - Lighter elements ‘want’ more (release E)
  - Heavier elements ‘want’ less (release E)
- Fission – Fragmenting of heavier nuclei
- Fusion – Joining together of light nuclei

22.6 Nuclear Fission & Fusion

- Nuclear Fission:
  - Urnaium-233, uranium-235, and plutonium-239
    - When struck w/ neutron break into fragments

22.6 Nuclear Fission & Fusion

- Critical Mass
- The amount is a self-sustaining chain reaction
  - ^{235}U= 56kg
  - Under pressure or surrounded (trap escaping neutrons) 15 kg



22.6 Nuclear Fission & Fusion

- Example: Calculate the energy released (kJ/mol) by the fission of uranium -235 to barium-142 & krypton-91.
  - Hint: Don't worry about electrons (same from products to reactants)
    - ^{235}U (235.0439 amu)
    - ^{142}Ba (141.9164 amu)
    - ^{91}Kr (90.9234 amu)
    - n (1.00866 amu)