Symbols of the Elements

- Symbol notation
  - Introduced by Berzelius
    - Based on the Latin name
  - Symbols now based on the English name
    - First letter capitalized, all others (if any) lower case
    - Know the elements listed in handout!

Symbols of the Elements

- Questions: 1 – 3
The Atomic Nucleus
- Atoms
  - Electrons – outside the nucleus
  - Protons – in the nucleus
  - Neutrons – in the nucleus
    - Protons and neutrons about the same mass
    - 2000x more massive than electrons
    - Nucleons

Symbols for Elements

- Mass number (A)
  - Number of nucleons present in an atom
  - Defines different isotopes for each element
- Atomic number (Z)
  - Number of protons (or electrons!) in each atom
  - Defines the element
- # Neutrons = A - Z

Symbols for Elements

Mass number
Atomic Number
Chemical Symbol

A
X
Z

# Neutrons = A - Z
Isotopes
- All have same chemical properties
- May differ slightly in physical properties
  - Hydrogen (H) $^1\text{H}$
  - Deuterium (D) $^2\text{H}$
  - Tritium (T) $^3\text{H}$

The Atomic Nucleus
- Atomic Mass Units (amu)
  - Based on $^{12}\text{C}$ atom = 12 amu (exactly)
  - $^{12}\text{C}$ (amu)
- Strong Nuclear Force
  - Holds positive charges in the nucleus together
  - Not completely understood
  - Force is overcome when more than 83 protons

The Atomic Nucleus
- Questions: 4 – 13
- Problem: 1
Radioactivity and Half-Life

- Radioactive isotope
  - Undergoes spontaneous decay
  - Radioactivity
- 3 types of decay processes
  - Alpha (α)
  - Beta (β)
  - Gamma (γ)

Radioactive Decay

- Alpha
  - Emits an alpha particle
    - 2 protons and 2 neutrons
    - Helium nucleus
  
  \[ ^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^4_2He \]

  In a nuclear equation, the sum of the mass numbers will be the same on both sides of the equation, as will the sum of the atomic numbers!

Nuclear Decay

\[ ^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{1}e \]

- Beta Decay
  - Note: the mass number for the beta-particle (electron) is zero (no nucleons) and the atomic number is -1 (negative charge)

\[ ^{206}_{82}Pb \rightarrow ^{206}_{82}Pb + ^0_1 \gamma \]

- Gamma Decay
  - With gamma decay, there is no change in mass number or charge. The gamma particle is in reality, a very high energy photon. The nucleus is in an excited state; similar to electrons in an excited state emitting photons when they return to the ground state!

\[ ^{11}_{7}F \rightarrow ^{11}_{8}O + ^{0}_{1}e \]

- Positron Emission
  - A positron is 'antimatter'. Positron emission usually occurs from artificial radioisotopes. When a positron meets an electron, BOTH are annihilated, and two gamma rays are emitted.
**Nuclear Decay**

- Almost all elements through Z=83 have at least one stable isotope
  - Exceptions are Tc (43) and Pm (61)
- All isotopes with Z>83 are radioactive
  - Undergoes a series of decays to end with a stable isotope

**Decay of Uranium-238**

![Decay of Uranium-238](image)

**Nuclear Stability**

- Band of Stability
  - Ratio of neutrons to protons
    - Slightly greater than 1:1
- Nuclear pairing
  - Even vs. Odd
Half-Life

- Individual decay is random
- Large numbers described statistically
- Half-Life
  - Time for $\frac{1}{2}$ of the nuclei in a sample to decay
  - 2 $\frac{1}{2}$ lives = $\frac{1}{4}$ original sample, etc...
  - Monitor with Geiger counter

Example

- How much of a 40-mg sample of iodine-131 (half life = 8 d) will remain after 24 days?
  - How many $\frac{1}{2}$ lives?
    - $24/8 = 3$
  - How much is left?
    - 40-mg (0) > 20-mg (1) > 10-mg (2) > 5-mg (3)
    - Fraction left = $\frac{1}{2}^3$ = $\frac{1}{8}$
    - $40 \times \frac{1}{2} = 40 \times \frac{1}{8} = 5$-mg

Carbon-14 Dating

- Levels of carbon-14 relatively constant
  - 16 counts per minute per gram; $\frac{1}{2}$ life = 5730 y
  - Produced in upper atmosphere from reaction of nitrogen
    - $^{14}_7N + _0^1h \rightarrow ^{14}_6C + ^1_1H$
- Can determine amount in formerly living carbon based materials and determine how much is left.
Example

- An ancient scroll found in a cave has a carbon-14 activity of 4 counts per minute per gram. Approximately how old is the scroll?
  - How many \( \frac{1}{2} \) lives?
    - 16 counts (0) > 8 counts (1) > 4 counts (2)
  - How long?
    - \( 2 \frac{1}{2} \) lives * (5730 years/ \( \frac{1}{2} \) life)
    - 11,460 years

Radioactivity and \( \frac{1}{2} \) Life

- Questions: 14 – 19
- Problems: 3 – 17 odd

Nuclear Reactions

- Transmutation
  - Elements change to different elements!
- Artificial transmutation
  - ‘Forcing’ a change
  - Rutherford
  - \( ^4He + ^4He \rightarrow ^8O + ^1H \)
  - Mass number and atomic number still conserved
Nuclear Reactions

- This is the dream of the alchemist!
  - Can turn mercury into gold
  - $^1H + ^{208}Hg \rightarrow ^{209}Au + ^4He$
  - Unfortunately, cost is > $1,000,000 per oz
- Transuranic elements all artificial
  - Also, Tc (43)

Uses

- Americium-241
  - Smoke detector
  - Smoke absorbs alpha particles: Stops current - triggers alarm
- Iodine-123
  - Monitor/modify thyroid
- Radioactive tracers
  - Carbon-14 and Tritium (Hydrogen-3)
  - Neutron Activation Analysis
    - Element identified by gamma ray emission
    - Anti-terror (Nitrogen determination)

Nuclear Reactions

- Questions: 20 – 22
- Problems: 19
Nuclear Fission

- Large nuclei are split into 2 smaller nuclei
- Neutrons are emitted
- Mass converted to energy
- Typically induced by nuclear bombardment

\[ ^{1}\text{H} + ^{235}\text{U} \rightarrow ^{236}\text{U} \]

**THEN**

\[ ^{235}\text{U} \rightarrow ^{136}\text{Xe} + ^{94}\text{Sr} + 2^{1}\text{n} \]

**OR**

\[ ^{238}\text{U} \rightarrow ^{132}\text{Sn} + ^{140}\text{Mo} + 3^{1}\text{n} \]

**OR**

\[ ^{235}\text{U} \rightarrow ^{95}\text{Kr} + ^{144}\text{Ba} + \_ \]

**OR...**

**Nuclear Fission**

- ‘Breaking’ Nucleus
  - Somewhat random as to the pieces that are formed
- Chain reaction
  - One formed neutrons are absorbed by other reactive nuclei – self-sustaining
  - If greater than 1 absorbed per decay, then we have EXPANDING CHAIN REACTION

**Nuclear Fission**

- Critical Mass
  - Mass required for an expanding chain reaction
  - Uranium-235 about 4 kg
    - Natural uranium only about 0.7% fissionable
    - Must be enriched for fission reaction
    - Power plant – about 3%
    - Weapons-grade – about 90%
- Atom bomb
  - Sub-critical massed are forced together to critical mass
Nuclear Reactors

- Controlled fission
  - Control rods absorb neutrons
  - Adjust to insure controlled process
- Reaction generates heat
  - Coolant is used to generate steam to turn turbines
  - Also serves as a moderator
    - Slows down neutrons

Meltdown!
- Not enough coolant
- Core melts through floor of reactor
  - Containment vessel
- Three Mile Island
  - Partial meltdown – small amount of radioactive nuclei escaped
- Chernobyl
  - Unauthorized experiment
  - Several (up to seven) safety interlocks were bypassed
  - Graphite moderator caught fire
  - Smoke carried radioactivity into environment

Breeder reactor
- Production of other fissionable material from uranium-235 reaction
  - Plutonium-239
  - Produced by ‘fast’ neutrons
- Usually higher temperatures
  - Liquid sodium as a coolant
Nuclear Fission

- Questions: 23 – 30
- Problems: 21

Nuclear Fusion

- Small nuclei combine to form larger ones
  - Process that fuels the Sun
  - $^4_1H \rightarrow ^4_2He + 2_1^0e + \text{energy}$
- No critical mass
  - Must overcome repulsive forces between nuclei
  - Plasma
    - Small enough volume for frequent collisions

Nuclear Fusion

- H-bomb
  - Uncontrolled
  - Fission bomb give energy to initiate fusion
- Controlled fusion elusive
  - Lowest temp. (D-T) about 100,000,000 K
  - Confinement problems
    - Inertial confinement
    - Magnetic confinement
Nuclear Fusion

- Still promising energy source
- Abundance of Deuterium
- Reduce nuclear waste
- No 'meltdown'

Where does energy come from?
- Direct conversion of mass to energy!
- $E = mc^2$
- HUGE amounts of energy from small mass conversion

Mass Defect

- For an atom, the mass of the parts is greater than the mass of the atom
  - For carbon-12
    - 6 protons = 6*1.00728 amu = 6.0437 amu
    - 6 neutrons = 6*1.00867 amu = 6.0520 amu
    - 6 electrons = 6*0.00055 amu = 0.0033 amu
    - Total = 12.0990 amu
    - Carbon-12 mass (by definition) = 12 amu (exactly)

What happened to the 0.0990 amu of mass?
- Converted to energy
- Factor is 931 MeV/u
- 92 MeV of energy
  - Energy source for the strong nuclear force
Binding Energy

- Calculate binding energy per nucleon
- Peaks at iron
  - Fusion gives energy for elements lighter than iron
  - Fission gives energy for elements heavier than iron

Nuclear Fusion

- Questions: 31 – 37
- Problems: 23

Hazardous Effects of Radiation

- Read Section 10.7
- Questions: 38
- Key Terms: Matching, Multiple Choice, and Fill-in-the-Blank Questions; Visual Connection and Applying your Knowledge