Nuclear Chemistry

I. What is nuclear chemistry?
   a. Nuclear changes vs. chemical changes
      i. A **nuclear** change is a change in which the nucleons (things in the nucleus) change. For instance, if the number of neutrons or protons in the nucleus changes, that is a nuclear change. A nuclear change often turns one element into another element. <u>A nuclear change is a change that occurs *within* the atom.</u>
         1. Example of a nuclear change:
            $^{1}n + {}^{14}N \rightarrow {}^{14}C + {}^{1}H$
            (By the way: This equation shows the formation of the isotope carbon-14. Nitrogen-14 captures a neutron to produce C-14, which is the isotope used in carbon dating. More on this later.)
      ii. A **chemical change** is a change in which atoms join together, split apart, or rearrange. <u>A chemical change involves breaking or forming bonds *between* atoms.</u>
         1. Example of a chemical change:
            $\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$
            (This just shows the burning of methane, which is basically the natural gas that we use in our Bunsen burners.)

II. Why do we care about nuclear chemistry?
   a. Nuclear power – we can harness the energy stored in the powerful bonds between protons and neutrons to turn the lights on in our houses.
   b. Nuclear weapons - we can harness the energy stored in the powerful bonds between protons and neutrons to destroy a city in less than one second.
   c. Archaeology – we can use the fact that all living things contain radioactive carbon to determine the age of fossils. This is called **carbon dating**.
   d. Radiochemistry and nuclear medicine – certain chemical reactions and lab tests make use of the fact that two different isotopes of the same element have the same chemical properties even though they have different nuclear properties.
   e. Cosmochemistry - the study of the chemical composition of and changes in the universe

III. A review of atomic structure
   a. Nucleus vs. electron cloud
      i. In this chemistry course, we are concerned with only three subatomic particles: the electron, the proton, and the neutron.
      ii. The protons and neutrons are located in the nucleus. The electrons are located outside the nucleus in the electron probability cloud.
      iii. Protons and neutrons are not involved in ordinary chemical reactions.
   b. Atomic number, mass number, and isotopes
      i. The atomic number of an element is the number of protons.

1. The atomic number (Z) of an element is shown in the lower left-hand corner of the element's symbol. The mass number (A) appears in the upper left-hand corner.

   $$^{A}_{Z}\text{Element Symbol}$$

   Examples:

   a. $^{4}_{2}\mathrm{He}$ The mass number is 4, the atomic number is 2.
   b. $^{238}_{92}\mathrm{U}$ The mass number is 238, the atomic number is 92.
   c. $^{14}_{6}\mathrm{C}$ The mass number is 14, the atomic number is 6
   d. $^{12}_{6}\mathrm{C}$ The mass number is 12, the atomic number is 6.

2. The atomic number is redundant when the element symbol is given, so it is often omitted.

   Examples of representing helium-4:

   $^{4}_{2}\mathrm{He}$ He-4 $^{4}\mathrm{He}$

   Examples of representing uranium-235:

   $^{235}_{92}\mathrm{U}$ U-235 $^{235}\mathrm{U}$

ii. ALL atoms of a given element have the same number of protons.
iii. Atoms that have the same number of protons and neutrons are identical nuclides.
iv. Atoms that have the same number of protons but different numbers of neutrons are **isotopes** of the same element.
v. Atoms that have different numbers of protons are atoms of different elements.

c. Nuclear properties vs. chemical properties

IV. Nuclear Changes

a. Radioactive decay

i. Alpha decay (α decay)

1. Emission of an alpha particle from the nucleus
2. An alpha particle is simply a Helium-4 nucleus (two protons, two neutrons, but no electrons)
3. Least penetrating particle; can be stopped with a sheet of paper

ii. Beta decay (β decay)

1. Emission of an electron from the nucleus
2. A beta particle is just an electron
   a. How did an electron get into the nucleus in the first place? A beta particle results when a neutron in the nucleus turns into a proton (which stays behind in the nucleus) and an electron (which gets shot out of the nucleus)
3. Beta particles are more penetrating than alpha particles; a beta particle can be stopped by a sheet of aluminum foil (but will not be stopped by a mere sheet of paper)

iii. Gamma decay (γ decay)

1. Emission of gamma radiation from the atom.
2. Radiation is just light. So, a gamma "particle" is a particle of light, which is called a photon.
3. Gamma radiation is very penetrating, and will be stopped only by lead or a similar material. Remember, gamma radiation is radiation that is even more powerful than X-rays.

b. Calculations involving radioactive decay
   i. Many isotopes of the elements that exist in nature are unstable to some degree. "Unstable" means that the atom is in a high state of potential energy and must change the composition of its nucleus in order to become more stable.
   ii. C-12 is an extremely stable isotope of carbon. C-14 is much less stable than C-12.
   iii. A way of describing the stability of an isotope is the **half-life** of that isotope
   iv. The half life of an isotope is the time that it takes for one-half of a sample of that isotope to decay to some other isotope. Examples:
      1. The half-life of C-14 is 5730 years
      2. The half-life of Po-210 is 138 days
      3. The half life of I-131 is 8.02 days
      4. The half life of Fr-223 is 22.0 minutes
   v. Calculating the amount of an isotope left after a specified length of time
      1. $\ln(N/N_0) = -kt$ is the formula for figuring out advanced calculations.
         a. "ln" stands for the operator "natural logarithm". It's a button on your calculator. You can find log of a number (log base 10) by pushing the "log" button on your calculator. Similarly, you can find the natural log of a number (log base "***e***", where ***e*** is approximately equal to 2.71828 . . .) by pushing the "ln" button of your calculator
         b. N = the amount of stuff left over after a certain amount of time has gone by.
         c. N_0 = the amount of stuff that you had to begin with (at time = 0)
         d. k = the decay constant for that isotope
         e. t = time that substance has been allowed to decay.
      2. There is another, easier way to do calculations involving radioactive decay. As long as the amount of time that the substance decays is some whole number multiple of the half-life, then you can figure out the amount of the substance that remains using pencil and paper.

Example:

Technetium-99 has a half-life of 6 hours, A 100 ug (microgram) sample of Tc-99 has been isolated for an experiment. After the experiment, how much of the Tc-99 remains if the experiment lasted 2.0 days?

Answer: $2.0 \text{ days} \times \frac{24 \text{ hours}}{1 \text{ day}} = 48 \text{ hours}$

48 hours = 8 half-lives,

Thus, the 100-ug sample will be "cut in half" 8 times,

$100 \div 2 \div 2 \div 2 \div 2 \div 2 \div 2 \div 2 \div 2 = \frac{100}{256} = 0.39$ ug

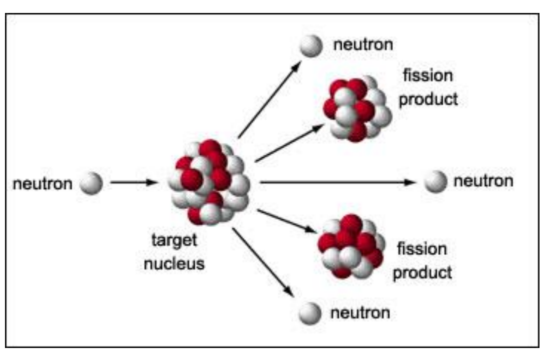
c. Fission

i. Fission is the splitting of a nucleus into two smaller nuclei.

ii. Fission occurs in nuclear power plants and in the original nuclear bombs dropped on Japan.

iii. Ideal fission fuel is large atom (U or Pu)

iv. Nuclear chain reaction



(If you are reading these notes online, click here to see a short movie depicting a nuclear chain reaction. If that link doesn't work, consult the *Documents* page and look for the movie under *Animations*.)

1. Nuclear bombs

        2. Nuclear power generation
            a. Fuel
            b. Moderators
            c. Control rods
  d. Fusion
    i. Fusion is the combination, or “fusing” of two nuclei to make one bigger nucleus.
    ii. Fusion occurs in the sun. Also, new nuclear bombs (the hydrogen bomb) use fusion. Scientists have not yet managed to use fusion in nuclear reactors, though they are trying.
    iii. H and Li are common starting products for fusion. He is a common product.
  e. Balancing nuclear equations

V. Uses of nuclear chemistry
  a. Nuclear power
    i. Why use nuclear power?
    ii. Types of power generation used in the US
    iii. Similarities between nuclear power generation and conventional fossil fuel-based power generation
    iv. Differences between nuclear power generation and conventional fossil fuel-based power generation
    v. Design of a nuclear power plant
    vi. Safety
        1. Safety record
        2. Safety concerns
            a. Meltdown
            b. Radioactivity leaks
        3. Waste disposal
            a. Environmental and human health concerns
            b. Transportation
            c. “NIMBY”
            d. Protection against theft for use in dirty bomb, etc.
  b. Nuclear weapons
    i. Fission bombs
    ii. Fusion bombs
    iii. Uranium enrichment
    iv. Depleted uranium
    v. Plutonium production
  c. Archaeology
  d. Radiochemistry
  e. Cosmochemistry

VI. Questions that you might have
  a. Nuclear arms

i. What's so special about atomic bombs? Why did the US build an atomic bomb during WWII? Didn't we have enough firepower (killing capacity) with conventional weapons?
ii. Why hasn't anyone used an atomic bomb since WWII?
iii. Why didn't the US drop nuclear bombs on Germany, the USSR, Korea, Viet Nam, Iraq, or Afghanistan?
iv. Why hasn't any other country developed an atomic bomb (or have they)? How many countries have an atomic bomb? Why don't more countries make atomic bombs and use them against us or each other?
v. How does the US determine if someone else is developing/buying/testing nuclear weapons?
vi. What is a dirty bomb?

b. Nuclear power
   i. Is nuclear power dangerous?
   ii. What is a nuclear reactor?
   iii. Public attitudes to nuclear power
      1. advocacy
      2. criticism
      3. impact of global warming
      4. impact of rising energy prices (ca. 2002 until present)
      5. impact of nuclear proliferation concerns
   iv. Nuclear waste
   v. Nuclear power disasters/accidents
      a. Three Mile Island
      b. Chernobyl
   vi. Alternative reactor designs
      a. Breeder reactors
      b. Pebble bed reactors

c. Uranium enrichment
d. Plutonium production