NUCLEAR CHEMISTRY

Chapter 21

http://youtu.be/KWAsz59F8gA

NUCLEAR VS CHEMICAL CHANGE

- Nuclear reactions involve the nucleus
- The nucleus opens, and protons and neutrons are rearranged.
- The opening of the nucleus releases a tremendous amount of energy that holds the nucleus together – called binding energy
- "Normal" chemical reactions involve electrons, not protons and neutrons
- Some of the mass can be converted into energy (mass defect)
  - Very famous equation of $E = mc^2$
  - Energy = E, Mass = m, speed of light = c

INTRO VOCABULARY

- Atomic nuclei are made of protons and neutrons, which are collectively called *nucleons*
- *Nuclear radiation* – particles or electromagnetic radiation emitted from the nucleus during radioactive decay
- *Radioactive nuclide* – an unstable nucleus that undergoes radioactive decay
- *Nuclear reaction* – a reaction that affects the nucleus of an atom
- *Transmutation* – a change in the identity of a nucleus as a results of a change in the number of its protons

RADIOACTIVE DECAY

- The spontaneous disintegration of a nucleus into a slightly lighter nucleus, accompanied by emission of particles, electromagnetic radiation, or both.
  - Unstable radioisotopes of one element can be turned into stable isotopes of a different element if the proton number changes.
    - Radioisotopes – radioactive isotopes that have an unstable nucleus.
    - Isotopes are atoms of the same element with different numbers of neutrons.
    - Stability of the nucleus depends on the ratio of the neutrons and protons.
  - Happens spontaneously – does not required any input of energy.

TYPES OF RADIATION

- **Alpha Radiation – Greek Letter α =** $^{4}_{2}He$
  - Consists of helium nuclei that have been emitted from a radioactive source
  - *Alpha particles*
    - *Contains two protons and two neutrons and have a double positive charge*
    - *When an atom loses an alpha particle the atomic number is decreased by 2 and the mass number is decreased by 4 (2p and 2n)*
    - *Properties of Alpha Particles:*
      - *Large*
      - *Restricted to happening to almost entirely very heavy nuclei*
      - *Slow moving*
      - *Easily stopped (paper or skin)*
      - *Danger if ingested, penetrates soft internal body tissues*

$$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$$

TYPES OF RADIATION

- Beta Radiation – Greek Letter β = ${}^{0}_{-1}e$
  - Consists of fast moving electrons formed by the decomposition of a neutron in an atom.
    - *Beta Particles*
      - The neutron breaks into a proton and electron
      - Beta is a fast moving electron ejected from the nucleus
        - The new proton stays in the nucleus
      - Properties of Beta particles:
        - Smaller than alpha particles
        - Faster than alpha particles
        - More penetrating than alpha particles. Can go through paper and skin. Stopped by aluminum foil and thin pieces of wood.

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta $$

TYPES OF RADIATION

- **Gamma Radiation – Greek Letter γ electromagnetic radiation**
  - Emitted by the nuclei of disintegrating radioactive atoms along with alpha and beta radiation
    - *Gamma Rays*
      - *Have no mass so they do not alter atomic number or mass number of an atom*
      - *Gamma rays are the same as x-rays except in their origin*
        - *X-rays are produced from excited electrons in certain metals losing energy, not from radioactive decay*
      - *Both gamma and x-rays pass easily through paper, the skin, and wood.*
      - *They can be stopped, but not completely by several meters of concrete or several centimeters of lead.*

$$^{14}{}_{6}C \rightarrow {}^{14}{}_{7}N + {}^{0}{}_{-1}\beta$$

TYPES OF RADIATION

- Positron Emission: ${}^{1}{}_{1}p \rightarrow {}^{1}{}_{0}n + {}^{0}{}_{+1}\beta$
  - *A particles that has the same mass as an electron, but has a positive charge, and is emitted from the nucleus during some kinds of radioactive decay.*
    - *To decrease the number of protons, a proton can be converted into a neutron by emitting a positron. Atomic number decreases by one, but the atomic mass stays the same.*

$$ {}^{38}{}_{19}K \rightarrow {}^{38}{}_{18}Ar + {}^{0}{}_{+1}\beta $$

- *Electron Capture:* ${}^{0}{}_{-1}e + {}^{1}{}_{1}p \rightarrow {}^{1}{}_{0}n$
  - An inner orbital electron is captured by the nucleus of its own atom.
    - The inner electron is combined with a proton and a neutron is formed. The atomic number decreases by one but the mass number stays the same.

$$ {}^{106}{}_{47}Ag + {}^{0}{}_{-1}e \rightarrow {}^{106}{}_{46}Pd $$

BALANCING NUCLEAR REACTIONS

- In the reactants and products:
  - Atomic number must balance

  AND
  - Mass number must balance

  - Use a particle or isotope to fill in the missing protons or neutrons if needed

WORKSHEET

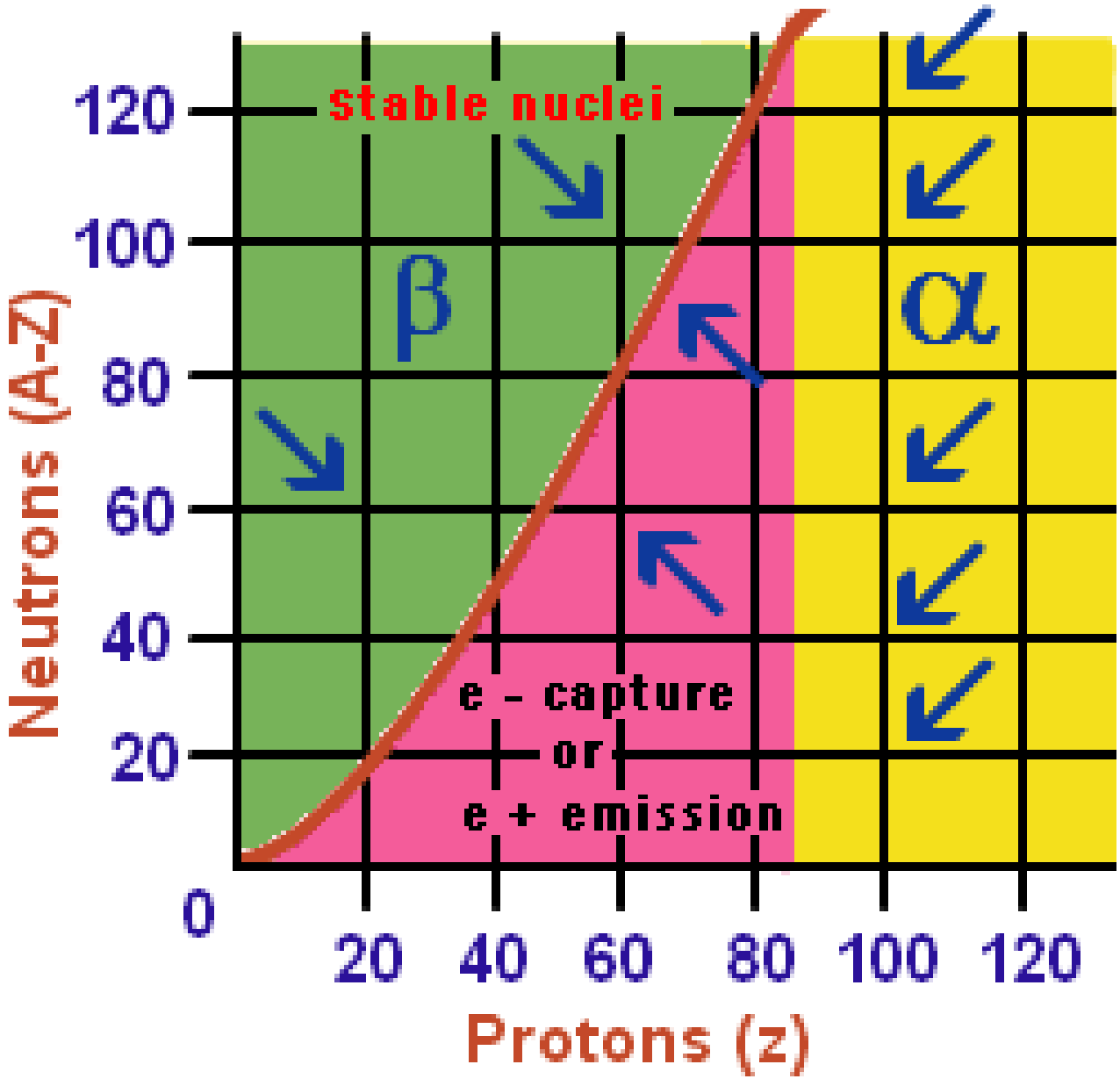
TRANSMUTATION REACTIONS

- Transmutation is the conversion of an atom of one element to an atom of another element
  - Can be done through radioactive decay
  - Can also occur if the nucleus is bombarded with high energy protons, neutrons, or alpha particles
  - Can occur in nature and be done in labs

- Transuranium elements are the elements in the periodic table with atomic numbers greater than 92
  - None occur in nature
  - All are radioactive

NUCLEAR STABILITY

- Stability depends on the proton to neutron ratio up to atomic number 20 the ratio is 1:1 (n:p) above atomic number 20 the ratio reaches 1.5:1.
  - Band of Stability – a neutron verses proton lot of stable nuclei (1500 nuclei are known but only 264 are stable!!)
    - Nuclei that fall outside the band of stability undergo spontaneous radioactive decay.
    - The type of decay depends on the position of the nucleus with respect to the band of stability.
      - Either too many protons or too many neutrons for the ratio – thus must be changed to be stable

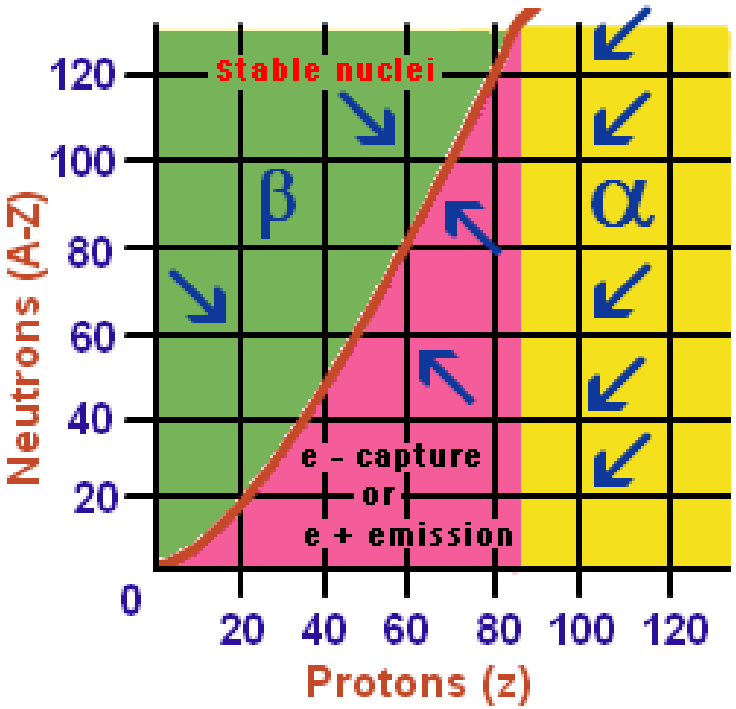

stable nuclei
β
α
e - capture
or
e + emission
Neutrons (A-Z)
Protons (z)
0
20
40
60
80
100
120

NUCLEAR STABILITY

- Alpha Emission
  - Above the band of stability (or beyond)
  - Too many protons and neutrons
    - The AN decreases by 2
    - The mass number decreases by 4 (2p, 2n)
    - All nuclei with an AN greater than 83 are radioactive. The majority of these undergo alpha emission.
- Beta Emission
  - To the left of the band of stability, the nuclei has to many neutrons
    - A neutron breaks into a proton and electron
    - Beta decay the e- is emitted from the nucleus
  - To the right (or under) of the band of stability, the nuclei has too many protons
    - A proton is converted to a neutron by capturing an electron
    - Beta capture an e- is absorbed

NUCLEAR STABILITY

- Positron
  - A particle with a mass of an electron but a positive charge.
    - A positron may be emitted as a proton is converted to a neutron
    - The AN decreases by one
    - The mass stays the same



NUCLEAR STABILITY GRAPHING ACTIVITY

NUCLEAR FISSION

- Fission is when the nucleus of certain isotopes are bombarded with neutrons, they split into small fragments.
  - Nucleus breaks into smaller pieces.
  - Neutrons are released, striking other atoms and creating a chain reaction.
  - Unleashes an enormous amount of energy.
  - If uncontrolled, the energy released is instantaneous.
    - Atomic Bombs

NUCLEAR POWER PLANTS

- Controlled Fission – releases energy more slowly and is done by nuclear reactors.
  - Much of the energy is generated as heat.
  - The heat is removed by coolant fluid.
  - Steam is generated to drive the turbine.
  - A spinning turbine generates electricity.

Steps to controlling fission…prevents overheating the reactors…

1. **Neutron moderation** – a moderator slows down the neutrons so that they do not hit the next uranium atom with as much force; therefore, reducing the number of uranium atoms being split.
2. **Neutron absorption** – control rods decreases the number of neutrons by absorption. This prevents too many uranium atoms being split at one time.

NUCLEAR FUSION

- Fusion occurs when two nuclei combine to produce a nucleus of heavier masses.
  - The Sun creates energy by solar fusion.
    - Two hydrogen nuclei fuse to form a single helium nucleus.
  - Releases more energy than fission.
  - Can only occur at an extremely high temperature
    - The Sun is greater the 40 million °C
    - https://youtu.be/FU6y1XIADdg?list=PL8dPuuaLjXtPHzzYuWy6fYEaX9mQQ8oGr

DETECTING RADIATION

- Radiation is hard to detect because it cannot be seen, heard, felt, or smelled.
  - Ionizing Radiation – radiation with enough energy to knock electrons off some atoms of the bombarded substance to produce ions.
  - The following devices are not protection but tools for detecting radiation:
    - Geiger Counter – gas filled metal tube to detect radiation
      - Used to detect beta and gamma radiation
      - Gas gets ionized when beta and gamma radiation penetrate glass
      - Gas flows, current flows, electronic counters click
    - Scintillation Counter – device that uses a specially coated phosphorus surface to detect radiation
      - Detects all types of radiation
      - Radiation hits the phosphorus surface and produces bright flashes of light
      - The light is converted to electronic pulses which are measured and recorded
    - Film Badge – layers of film covered with black lightproof paper in plastic holder
      - Film is removed and developed at regular intervals
      - Strength and type of radiation are determined by the darkening film

USING RADIATION

- Neutron Activation
  - Detects trace amounts of elements in samples
  - The half-life and type of radiation emitted is unique for each element
- Cancer Treatments
  - Cancer is abnormal cells produced at a faster rate than healthy cells
  - Tumor is a runaway growth of cancerous cells in one area
  - Fast-growing cancer calls are damaged more then healthy cells by gamma radiation
  - Gamma radiation will also kill healthy cells to some degree
    - Applied with a laser beam, or implanted salt/gold tubes
- Radio-isotope Tracers
  - Agriculture Research –
    - Tracer connects to substance being tested, plants are treated with the radioactive substance
    - Measure quantity taken up by the plant.
    - Monitor quantity in animals, water, and soil
    - Determine locations over time of the radioactive substances
  - Disease Diagnosis –
    - Specific radio isotopes target specific chemicals in the body
      - Iodine-131 detects thyroid problems
      - Technetium-99 detects brain tumors and liver disorders
      - Phosphorus – 32 detects skin cancer