# Honors Chemistry Chapter 21 Nuclear Chemistry

**Section 1 The Nucleus pgs. 681-684.**

**Objectives:**

1. **Explain what a nuclide is, and describe the different ways nuclides can be represented.**
2. **Define and relate the terms mass defect and nuclear binding energy.**
3. **Explain the relationship between number of nucleons and stability of nuclei.**
4. **Explain why nuclear reactions occur, and know how to balance a nuclear equation.**

**Vocabulary: Define the following.**

1. **nucleon--**

2. **nuclide--**

3. **mass defect--**

4. **nuclear binding energy--**

5. **nuclear shell model--**

6. **magic numbers--**

7. **nuclear reaction--**

8. **transmutation--**

**In Chapter 3 it was discovered that the name of the particles composing the nucleus, the protons and neutrons are called nucleons and the atom itself is the nuclide. When the total amount of neutrons, protons, and electrons are added together and compared to the actual mass of the nuclide, there is mass missing. This mass was converted to energy to form the nucleus and is called the mass defect. The energy re-**

**leased when a nucleus is formed is called the nuclear binding energy and can be calculated using Einstein's famous formula of $E = mc^2$.**
**Review the example on pg. 681 to answer question 2 at the end of this section.**

**The nuclear binding energy measures the stability of a nucleus such that the greater the binding energy per nucleon the more stable the nucleus.**

**Iron is the most stable nucleus, and all the elements from hydrogen to iron were produced in a average size star. The other heavier elements were formed during the explosion or nova of a star. The heaviest elements were formed in supernovas.**

**The plot on a graph of the number of neutrons to protons produces a band called the band of stability. ***The most stable nuclei are those with a 1:1 ratio of neutrons to protons. Elements of intermediate mass have the greatest nuclear binding energies per particle, and both light and heavy elements have relatively small nuclear binding energies per particle.**

**There are two forces at work within a nucleus. The first force is the repulsive force of protons due to like charge. If the protons are close enough to each other the attractive nuclear force occurs.**
**As the nuclei become larger the repulsive force increases faster than the nuclear force.**
**Beyond bismuth #83 no stable nuclei exist.**
*****The most stable nuclei have even numbers of protons and neutrons.**
**This seems to indicate that nucleons exist in energy levels much like electrons called the nuclear shell model. The completed nuclear energy levels that are the most stable contain protons, neutrons or total nucleons of 2, 8, 20, 28, 50, 82 and 126. These numbers of nucleons are called the magic numbers.**

**Chemical reactions occur within the electron cloud when electrons are shared, given up or taken by 2 or more atoms while nuclear reactions only occur in the nucleus.**

**When a nuclear reaction occurs and if there is a change in the number of protons the identity of the atom has been change. This change of identity is called transmutation. Nuclear reactions are represented by nuclear equations. In a nuclear equation the total atomic numbers and the total mass numbers must be equal on both sides of the equation.**
**For example look at in the nuclear reaction:** $^{212}_{84}Po \rightarrow {}^{4}_{2}He + {}^{208}_{82}Pb$

**If the atomic numbers and atomic masses of the helium and lead are added they equal the atomic number and mass of the polonium.**

**Answer the following questions.**

1. **How is nuclear stability related to the neutron-proton ratio?**

2. **The mass of a $^{20}_{10}$Ne atom is 19.992 44 amu. Calculate the atom's mass defect.**

3. **Scientists believe that immediately after the big bang the nuclei of many of the elements were formed. What energy was released during this conversion of nucleons to nuclei?**

**Section 2 Radioactive Decay pgs. 685-692.**

**Objectives:**

1. **Define and relate the terms radioactive decay and nuclear radiation.**
2. **Describe the different types of radioactive decay and their effects on the nucleus.**
3. **Define the term half-life, and explain how it relates to the stability of a nucleus.**
4. **Define and relate the terms decay series, parent nuclide, and daughter nuclide.**
5. **Explain how artificial radioactive nuclides are made, and discuss their significance.**

**Vocabulary: Define the following.**

1. **radioactive decay-**

2. **nuclear radiation--**

3. **radioactive nuclide--**

4. **alpha particle--**

5. **beta particle--**

**6. positron--**

**7. electron capture--**

**8. gamma ray--**

**9. half-life--**

**10. decay series--**

**11. parent nuclide--**

**12. daughter nuclide--**

**13. artificial transmutation--**

**14. transuranium element--**

**<u>Radioactive Decay</u>**

**Henri Becquerel discovered in 1896 that uranium compounds give off x-rays. Marie and Pierre Curie discovered two new radioactive compounds polonium and radium in 1898.**

**In radioactive decay radioactive nuclides undergo spontaneous disintegration producing lighter nuclides, nuclear radiation which is the emission of particles, electromagnetic radiation or both.**

**<u>Types of radioactive decay</u>**

**1. <u>Alpha emission</u>. Only occurs in heavy nuclei. An alpha particle symbol, α, is emitted.**

**α is a helium nucleus minus 2 electrons. Written $^{4}_{2}He$. In alpha emission the mass number decreases by 4 and the atomic number decreases by 2.**

**Write the example from the text p. 686 here.**

***Example:

2. Beta emission. Occurs in nuclides with too large a neutron- proton ratio. The beta particle symbol is β. In beta emission a neutron is lost as it breaks down into a proton and an electron. Written as
$^{1}_{0}n$. Mass number stays the same, atomic number increases.

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta$$

Write example p. 686 here.
***Example:

3. Positron emission. Occurs in nuclides with too small of a neutron-proton ratio. A proton is changed to a neutron by emitting a positron. Positrons have the same mass of an electron, but with a positive charge. Written $^{1}_{1}p$. Atomic number decreases by 1, mass number stays the same.

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta$$

Write example from p. 687 here.
***Example:

4. Electron capture. This type of decay also occurs when the neutron to proton ratio is too small. In electron capture an inner electron is captured by the nucleus and combines with a proton to form a neutron.

$$^{0}_{-1}e + {}^{1}_{1}p \rightarrow {}^{1}_{0}n$$

Write the example from p. 687 here..
***Example:

Complete and balance the following. Use $^{1}_{0}n$ for a neutron and $^{0}_{-1}e$ for an electron.

Fill in the blank space with the correct answer.

**a.** $^{187}_{75}Re$ + ____ → $^{188}_{75}Re$ + $^{1}_{1}H$

**b.** $^{9}_{4}Be$ + $^{4}_{2}He$ → ___ + $^{1}_{0}n$

**c.** $^{22}_{11}Na$ + ____ → $^{22}_{10}Ne$

**d.** $^{234}_{90}Th$ → $^{0}_{-1}\beta$ + _______ **What type of decay is this?** __________

**e.** ________ → $^{4}_{2}He$ + $^{234}_{90}Th$ **What type of decay is this?** _____________

**f.** $^{15}_{8}O$ → ______ + $^{15}_{7}N$ **What type of decay is this?** ________

**g.** $^{22}_{11}Na$ + _______ → $^{22}_{10}Ne$ **What type of decay is this?** ________

**5. Gamma emission. Gamma rays are symbolized by the Greek letter γ. Gamma emission does not involve any subatomic particles but is instead the release of high-energy electromagnetic waves. Gamma rays are the highest energy radiation known.**

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**Half-Life**

**Half-life, symbolized, $t_{½}$, is the time required for half the atoms of a radioactive nuclide to decay. Each radioactive element has its own unique half-life. Some take millions or even billions of years to decay. The result of the decay is the formation of a new element.**

**At the end of the 19th century the age of the earth was estimated to be about 20 million years old. By the beginning of the 20th century the earth was thought to be in the hundreds of millions of years old. Scientists of that time period began studying crystals containing radioactive isotopes, specifically uranium-238 which has a half-live of 4.46 x $10^9$ years.**

**When uranium decays one of its major decay products is lead. By studying the ratio of lead to uranium it was determined that the earth was far older or about 4.6 billion years. This discovery has stood the test of time and today is considered the most accurate age of the earth.**
**Table 2 on p. 688 shows that the most unstable nuclides have the shortest half-lifes.**

**Solving half-life problems.**

**Problem 1. Given the half-life of a nuclide, the beginning mass of the nuclide and the time elapsed, and asked for the mass remaining.**

**Step 1: Divide the time elapsed by the half life to obtain the number of half lifes the nuclide has decayed.**
**Step 2: Take the given mass and multiply by ½ the number of times obtained in step 1.**
**Example: The half-life of polonium-210 is 138.4 days. How many milligrams of polonium-210 will remain after 415.2 days if you start with 2.0mg.**
**Solution:**
**Step 1: 415.2 days ÷ 138.4 days = 3 Step 2: 2.0mg x ½ x ½ x ½ = 0.25 mg**

**Problem 2. Given the fraction left after a certain given time find the half life.**
**Step 1: Find the number of half-lifes the fraction represents.**
**Step 2: Divide the time given by this integer.**
**Example: Exactly 1/16 of a given amount of protactinium-234 remains after 26.76 hours. What is the half-life?**
**Solution:**
**Step 1: 1/16 = ½ x ½ x ½ x ½ This is equal to 4 half-lifes. Or you may use the algebraic symbol for half-life $[1/2]^n$. So that $[1/2]^n = 1/16$, so n =4**
**Step 2: 26.76 hours ÷ 4 = 6.69 hours**

**Problem 3. If A) the amount of the nuclide present initially and B) the amount of nuclide that remains and C) the time for the original mass to decay is known, than the half-life can be determined.**
**Example: It takes 5.2 min for a 4.0 g sample of francium-210 to decay until only 1.0 g is left. What is the half-life of francium-210?**
**Solution:**
**Step 1: Find the fraction of the original mass remaining. 1.0g/4.0g = ¼.**
**Step 2: Find the number of half-lifes that have passed. $[½]^n = ¼$ so n =2 or 2 half-lifes have passed. Note $[½]^n$ is the number of half-lifes for all problems of this nature.**
**Step3: Divide the half-lifes passed by the time given.**

**5.2 min ÷ 2 = 2.6min.**
**Answer the following questions.**
**1. After 4797 years, how much of the original 0.250g of radium-226 remains? The half life of radium-226 is 1599 years.**

**2. The half-life of radium-224 is 3.66 days. What was the original mass of radium-224 if 0.0500g remains after 7.32 days?**

**3. The half-life of thorium-227 is 18.72 days. How many days are required for ¾ of a given amount of thorium-227 to decay?**

**Decay Series**

**A decay series is produced by a successive radioactive decay of the heaviest nuclide called the parent nuclide until a stable nuclide reached. All in intermediate nuclides are called daughter nuclides. The daughter nuclei decay by emitting either alpha or beta particles.**

**All naturally occurring nuclides with atomic numbers greater than 83 are radioactive and belong to one of three natural decay series. The parent nuclides of these decay series are uranium-238, uranium-235, and thorium-232.**
**For instance the decay series of uranium-238 occurs when uranium-238 first decays to thorium-90, which in turn decays to palladium-234, after 24 days palladium-234 will decay to uranium-234. This decay will continue until the stable isotope lead-206 is reached, which contains the magic number 82 and therefore has a stable nucleus.**
**What is the decay nuclide of radium-226?**
**Answer:**

**Write the nuclear equation for the reaction above including the particle emitted.**
**Answer:**

**<u>Artificial Transmutations</u>**

**Artificial radioactive nuclides are manmade and not naturally found on earth. These nuclides are made by particle accelerators, which are extremely large facilities sometimes miles in circumference that use magnetic fields to accelerate particles at speeds close to the speed of light. These accelerators have produced the transuranium elements greater than #92.**

**Answer the following to test your knowledge of this section.**

**1. List the 5 types of radioactive decay.**

**2. Which of the above is a helium nucleus?**

**3. Which of the above is an electron?**

**4. Why does the overall electric charge of the atom not change during beta emission?**

**5. Describe the energy of gamma radiation in relationship to X-rays.**

**6. What two nuclides are used to produce lawrencium-258? See table pg. 692.**

**7. What fraction of a given sample of a radioactive nuclide remains after four half-lives?**

**8. How does the neutron-proton ratio determine whether beta emission and positron emission occurs?**

**9. In what type of nuclei does alpha emission occur?**

**Sections 3 and 4 Nuclear Radiation and Nuclear Fission and Fusion, pgs. 693-699.**
**Students should read these two sections for background into nuclear radiation with the following objectives. These sections will not be discussed in lecture but are the responsibility of the student to have read the material and know the vocabulary.**
**Objectives:**
1. **Compare the penetrating ability of alpha, beta, and gamma rays.**
2. **Distinguish between roentgen and rem.**
3. **Discuss the applications of radioactive nuclides.**
4. **Distinguish between nuclear fission, chain reaction, and nuclear fusion.**

**Vocabulary: Define the following.**
1. **roentgen--**
2. **rem--**
3. **film badge--**
4. **Geiger-Muller counter--**
5. **radioactive dating--**
6. **radioactive tracer--**
7. **nuclear waste--**
8. **nuclear fission--**
9. **nuclear fusion--**
10. **chain reaction--**

**11. critical mass--**

**12. control rod--**