Ms. Randall
Regents Chemistry
Unit 13 Nuclear Chemistry

Unit Objectives
Upon completion of the unit students should be able to:

- Predict the stability of an isotope based on the ratio of neutrons and protons in its nucleus.
- Understand that while most nuclei are stable some are unstable and spontaneously decay emitting radiation.
- Calculate the initial amount of the fraction remaining, or the half life of a radioactive isotope, using the half life equation.
- Understand the concept of half life.
- Differentiate between the following emissions based on mass, charge, ionizing power, and penetrating power: Alpha, Beta, Positron, and Gamma
- Determine the type of decay (alpha, beta, positron, and gamma) and write the nuclear equations.
- Compare and contrast fission and fusion reactions
- Distinguish between natural and artificial transformations.
- Complete nuclear equations and predict missing particles from nuclear equations.
- Understand the change in energy in a nuclear reaction.
- Be aware of the risks associated with radioactivity.
- Recognize the beneficial uses and real world application of radioactive isotopes.
- Radioactive dating
- Tracing chemical and biological processes
- Industrial measurement
- Nuclear power
- Detection and treatment of diseases

Focus Questions for the Unit:
What determines nuclear stability?
How does an unstable element stabilize?

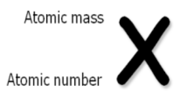
YOU SHOULD BE ABLE TO ANSWER THESE *IN DETAIL* BY THE END OF THE UNIT
Define the following vocabulary:

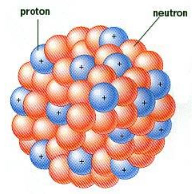
- **Artificial transmutation**
- **Atomic Mass Unit (amu)**
- **Atomic number**
- **Half-life Isotope**
- **Mass number**
- **Radioactivity** (Radioactive Decay)
- **Nuclear charge**
- **Nuclear fission**
- **Nuclear fusion**
- **Average Weighted Mass**
- **Tracer**

Lesson 1: <u>Radioactivity</u>

<u>Objective:</u> To determine rates of decay or remaining element based on half lifes of unstable elements

Review: Isotopes are atoms of the same <u>element</u> that have the same # of <u>protons</u> but different # of <u>neutrons</u> or <u>mass.</u>



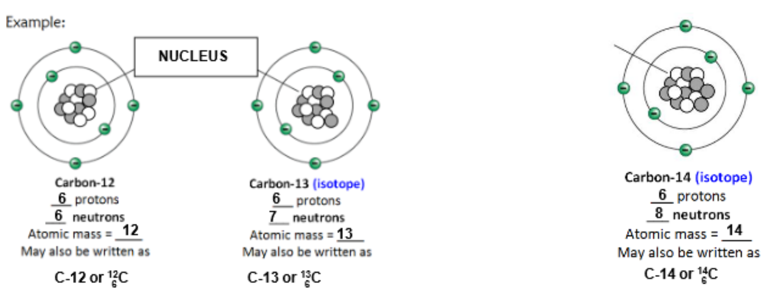


<u>Stability of Nuclei:</u>

- Large atoms are considered elements with an atomic > 83. They are naturally radioactive due to an unstable nucleus (due to the ratio of protons/neutrons being unstable).They have no known stable isotopes so they are continually decaying

- In small atoms the nucleus is stable and therefore are NOT naturally radioactive (atomic number is less than 83).
- Exception to "Small Atom Rule:" -When an atom's mass is not its typical mass (is an isotope of the mass seen on Periodic Table), the atom will be radioactive (unstable).

Example: C-12, C-13 & C-14



Radioactive isotopes are unstable, which means that they spontaneously (readily) decay (break apart) into different isotopes or elements. Radioactive isotopes give off radiation during the process of radioactive decay. Radiation can be in the form of particles (alpha, beta, or positron) and/or pure energy (gamma rays).

For radioactive isotopes, the rate (speed) of radioactive decay is constant. All radioactive isotopes have a specific **half-life**, or **<u>time</u> that it takes for exactly half of the sample to decay into something else and half of the sample to remain unchanged.** It is because of information about half-lives that we can know how old the Earth is and how old fossils are.

<u>Nuclear Chemistry</u> is the study of reactions that are caused by a change in the nucleus of an atom. It has nothing to do with electrons, just the nucleons (protons and neutrons)

- Natural radioactivity occurs when nuclei are unstable.
- For any element, an isotope that is unstable is called a **radioisotope.**
- A **Geiger counter** can be used to detect radiation given off by radioactive isotopes.

- Half-life is constant and can never be changed
- The amount of substance will NEVER decay to zero (you can always cut an amount in half, no matter how tiny)
- Each radioisotope has a specific **decay mode** (alpha, beta, etc.) and half-life (rate of decay) listed on **Table N**

Table N
Selected Radioisotopes

Nuclide	Half-Life	Decay Mode	Nuclide Name
^{198}Au	2.69 d	β^-	gold-198
^{14}C	5730 y	β^-	carbon-14
^{37}Ca	175 ms	β^+	calcium-37
^{60}Co	5.26 y	β^-	cobalt-60
^{137}Cs	30.23 y	β^-	cesium-137
^{53}Fe	8.51 min	β^+	iron-53
^{220}Fr	27.5 s	α	francium-220
^{3}H	12.26 y	β^-	hydrogen-3
^{131}I	8.07 d	β^-	iodine-131
^{37}K	1.23 s	β^+	potassium-37
^{42}K	12.4 h	β^-	potassium-42
^{85}Kr	10.76 y	β^-	krypton-85
^{16}N	7.2 s	β^-	nitrogen-16
^{19}Ne	17.2 s	β^+	neon-19
^{32}P	14.3 d	β^-	phosphorus-32
^{239}Pu	2.44×10^4 y	α	plutonium-239
^{226}Ra	1600 y	α	radium-226
^{222}Rn	3.82 d	α	radon-222
^{90}Sr	28.1 y	β^-	strontium-90
^{99}Tc	2.13×10^5 y	β^-	technetium-99
^{232}Th	1.4×10^{10} y	α	thorium-232
^{233}U	1.62×10^5 y	α	uranium-233
^{235}U	7.1×10^8 y	α	uranium-235
^{238}U	4.51×10^9 y	α	uranium-238

ms = milliseconds; s = seconds; min = minutes;
h = hours; d = days; y = years

Half-Life

Radioactive substances decay at a rate that is not dependent on temperature, pressure, or concentration. The **Half-life** is the time it takes for half the atoms in a given sample of an element to decay. The **shorter the half life** of an isotope **the less stable** it is.

The **longer the half life** of an isotope the **more stable** it is.

Table N lists common radioactive isotopes as well as their half-lives and modes.

We can use table N to answer questions about rates of decay.

Example: A sample of I-131 decays to 1.0 grams in 40 days. What was the mass of the original sample?
Half-life of I-131 from Table N =8.07 days. 40days/8 days=<u>5 half life decays</u>

½ ½ ½ ½ ½

1.0g→2.0g→4.0g→8.0g→16.0g→<u>32.0g</u>

Example: What is the total number of hours required for Potassium-42 to undergo three half life periods?
From Table N K-42 half life=12.4 hours

12.4 hours x 3= <u>37.2 hours</u>

Example: What mass of a 32.0 g sample of ^{32}P will remain after 71.5 days of decay?

From Table N half-life of P-32=14.3days 71.5 days/14.3 days=<u>5 half lives</u>

½ ½ ½ ½ ½

32.0g→16.0g→8.0g→4.0g→2.0g→<u>2.0g</u>

Radioisotopes are used for various things:

- *Smoke detectors*
- *C-14 tracer for living systems and organic reaction mechanisms. Carbon dating rocks/ages of fossils*
- *Tc-99 brain tumors*
- *I-131 Thyroid disease*
- *Radium and Co-60 cancer treatment*
- *Measure thickness of industrial products*
- *Sterilize food supplies(kills bacteria and molds)*
- *U-238 dating fossils*

Radioactive Isotopes: Uses & Dangers

Radioactive isotopes have many **beneficial uses**, such as

- **radiocarbon dating (carbon-14) (finding the age of once-living things)**
- **U-238 & Pb-206 (finding age of rocks)**
- **tracing** chemical and biological processes
- **nuclear power**
- detection and treatment of **disease**
  - ***Iodine-131*** *for* ***thyroid cancer***
  - ***Strontium-89*** *for* ***bone cancer***
  - ***Cobalt-60*** *for* ***other cancers***

MEDICINE

Radioisotope	Medical Function	Uses
Fluorine-18	Tracer (PET Scan)	Cancer detection/evaluation, cardiac and brain imaging
Iodine-131	Radionuclide Therapy (RNT)	Thyroid cancer treatment
Iridium-192	Radionuclide Therapy (RNT)	Head and breast cancer treatment
Strontium-89 samarium 153 Rhenium-186	Pallative	Pain relief
Technetium-99m	Diagnostic Radiopharmaceuticals	Monitoring organ function

(http://www.world-nuclear.org/info/inf55.html)

Lesson 2: Transmutation

Objective: To compare and contrast the reactants and products of nuclear decay reactions.

Transmutation is defined as the changing of a nucleus of one element into the nucleus of another element (by gaining or losing nucleons). This change always turns the unstable element into a more stable element. There are two types of transmutation.

Natural Transmutation Begins with one **unstable nucleus** that **spontaneously decays.** These reactions always have ONE REACTANT.

$$^{226}_{88}Ra \rightarrow {}^{4}_{2}He + {}^{222}_{86}Rn$$

Artificial Transmutation is caused by **bombarding** a **stable nucleus** with **high energy particles.** These reactions always have TWO REACTANTS**.**

$$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$$

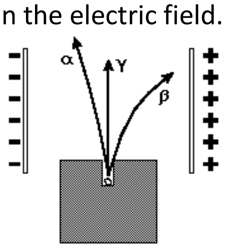
A. Two Types of Transmutation

Natural Transmutation	Artifical Transmutation
➢ happens spontaneously/on its own in nature *only 1 reactant*	➢ involves the bombardment (hitting) of atoms with other particles *2 reactants*
Example $^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}e$	Example $^{4}_{2}He + {}^{27}_{13}Al \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$

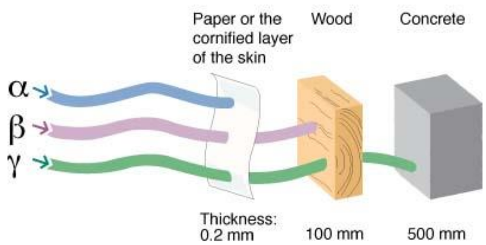
Transmutation of one element into another requires a change in the structures of the *nuclei* of the atoms involved. This results in the release (or gain) of radioactive decay particles.

How are the particles defined?

- Alpha, Beta and Gamma can be separated using an electric or magnetic field
- Positively charged alpha (α) particles move toward the negative.
- Negatively charged beta (β^-) particles move toward the positive
- Gamma rays and neutrons do not bend in the electric field.



Particle	*Mass*	*Charge*	*Symbol*	*Penetrating Power*	*Hazard*
Alpha	**4 amu**	**2+**		**Low**	**No external hazard, internal hazard!**
Beta	**0 amu**	**1-**		**Moderate**	**Dangerous internally and externally**
Positron	**0 amu**	**1+**		**Moderate**	**Dangerous internally and externally**
Gamma	**0 amu**	**None**		**High**	**Very dangerous highly penetrating**



<u>Writing Nuclear Equations</u>

Nuclear reactions obey laws of <u>conservation</u> of <u>mass and</u> <u>charge</u>.

The sum of the atomic masses and atomic numbers of the reactants= the sum of the atomic masses and atomic numbers of the products. The decay modes can be found on Table N.

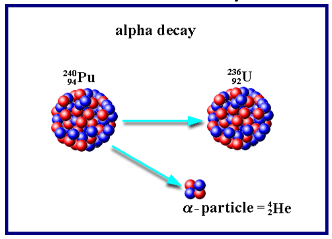
$$^{235}_{92}U \rightarrow {}^{4}_{2}He + {}^{231}_{90}Th$$

Table O
Symbols Used in Nuclear Chemistry

Name	Notation	Symbol
alpha particle	$^{4}_{2}He$ or $^{4}_{2}\alpha$	α
beta particle (electron)	$^{0}_{-1}e$ or $^{0}_{-1}\beta$	β^-
gamma radiation	$^{0}_{0}\gamma$	γ
neutron	$^{1}_{0}n$	n
proton	$^{1}_{1}H$ or $^{1}_{1}p$	p
positron	$^{0}_{+1}e$ or $^{0}_{+1}\beta$	β^+

1. Alpha Decay: when an unstable nucleus emits an alpha particle, this is called alpha decay

Alpha decay: mass decreases by four, atomic number decreases by two.

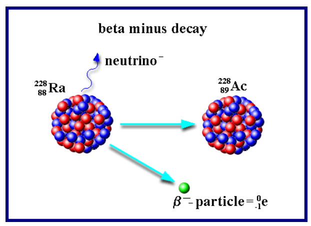


Example:
^{238}U undergoes alpha decay

$_{92}^{238}U \longrightarrow {}_{2}^{4}He + {}_{90}^{234}Th$

The total mass on the left must equal the total mass on the right (238 = 4 + 234)
The total charge on the left must equal the total charge on the right (92 = 2 + 90)

2. Beta decay: When an unstable nucleus emits a beta particle, this is called beta decay

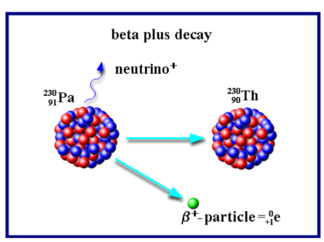


Beta (minus) decay: mass remains the same, atomic number increases by one.
Example:
^{234}Th undergoes beta decay

$_{90}^{234}Th \longrightarrow {}_{-1}^{0}e + {}_{91}^{234}Pa$

The total mass on the left must equal the total mass on the right (234 = 0 + 234)
The total charge on the left must equal the total charge on the right (90 = -1 + 91)

3. Positron Emission: When an unstable nucleus emits a positron, it is called positron emission



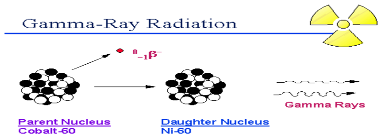
Positron (beta plus) decay: mass remains the same, atomic number decreases by one.
Example:
^{37}K undergoes positron decay

$_{19}^{37}K \longrightarrow {}_{+1}^{0}e + {}_{18}^{37}Ar$

The total charge on the left must equal the total charge on the right (19 = 1 + 18)

The total of the mass numbers on the left must equal the total on the right (37 = 0 + 37)

4. Gamma Rays: a highly penetrating type of nuclear radiation, similar to x-rays and light
Gamma rays have no mass and no charge, just energy. This makes them the most destructive form of nuclear radiation.

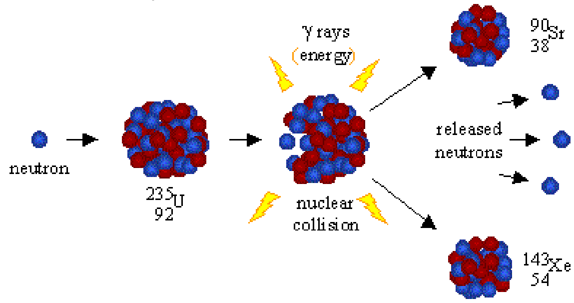


<u>Lesson 3:</u> <u>Energy and Nuclear Reactions</u>

<u>Objective:</u> To compare and contrast the reactants and products of fusion and fission nuclear reactions

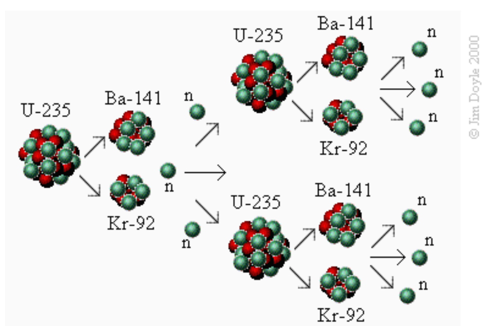
Nuclear fusion and **nuclear fission** are two different types of energy-releasing reactions in which energy is released from high-powered <u>atomic bonds</u> between the particles within the nucleus. The main difference between these two processes is that fission is the splitting of an atom into two or more smaller ones while fusion is the fusing of two or more smaller atoms into a larger one.

<u>Fission Reactions</u> involve the splitting of a heavy nucleus to produce lighter nuclei.
Fission reactions produce/capture neutrons. They can become involved in another fission reaction.



$^{235}U + ^{1}n \quad ^{90}Sr + ^{143}Xe + 3\,^{1}n$

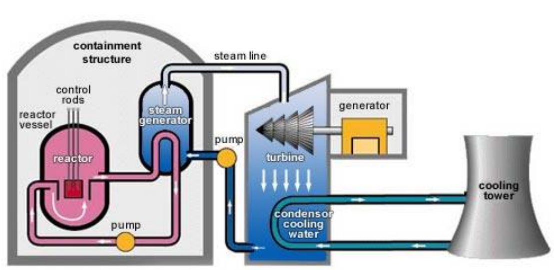
More neutrons are released to keep the reaction going. If the number of neutrons released is not controlled a chain reaction will occur. This is the type of reaction used in nuclear bombs.



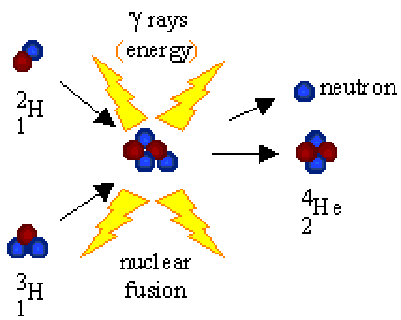
NOTE: ENERGY is also produced in the above nuclear reaction

All nuclear reactors are devices designed to maintain a <u>chain reaction</u> producing a steady flow of <u>neutrons</u> generated by the <u>fission</u> of heavy nuclei. When there is a loss of control over the chain reaction bad things happen!

<u>Fukushima</u>
<u>Click to</u> <u>Watch this</u>



<u>Fusion Reactions</u> involve the combining of nuclei to produce heavier ones.



$^{2}H + ^{3}H \rightarrow ^{4}He + ^{1}n$

Hydrogen atoms combine to form helium in a star.

In fission and fusion reactions, there appears to be a loss of mass. However, this mass has been converted to energy by the equation $E = mc^2$. This is known as the **mass defect.**

The energy of nuclear reactions is much greater than the energy associated with chemical reactions.

- One disadvantage of Fission → thermal pollution is a byproduct
- Disadvantages of Fusion → Need to overcome the need for extreme heat, hard to "control" the reaction

2 Types of Nuclear Reactions:

Fission	Fusion
•splitting LARGE (high mass) nuclei apart *•atomic bombs and nuclear power plants*	*•joining LIGHT (low mass) nuclei together* *•sun* *requires high temperatures to get the (+) nuclei to hit
Example $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^{1}_{0}n$ + ENERGY	Example $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ + ENERGY

	Nuclear Fission	**Nuclear Fusion**
Definition:	Fission is the splitting of a large atom into two or more smaller ones.	Fusion is the fusing of two or more lighter atoms into a larger one.
Natural occurrence of the process:	Fission reaction does not normally occur in nature.	Fusion occurs in stars, such as the sun.
Byproducts of the reaction:	Fission produces many highly radioactive particles.	Few radioactive particles are produced by fusion reaction, but if a fission "trigger" is used, radioactive particles will result from that.
Conditions:	Critical mass of the substance and high-speed neutrons are required.	High density, high temperature environment is required.
Energy Requirement:	Takes little energy to split two atoms in a fission reaction.	Extremely high energy is required to bring two or more protons close enough that nuclear forces overcome their electrostatic repulsion.
Energy Released:	The energy released by fission is a million times greater than that released in chemical reactions; but lower than the energy released by nuclear fusion.	The energy released by fusion is three to four times greater than the energy released by fission.
Nuclear weapon:	One class of nuclear weapon is a fission bomb, also known as an atomic bomb or atom bomb.	One class of nuclear weapon is the hydrogen bomb, which uses a fission reaction to "trigger" a fusion reaction