Nuclear Chemistry

These Notes are to SUPPLIMENT the Text, They do NOT Replace reading the Text Book Material. Additional material that is in the Text Book will be on your tests! To get the most information, READ THE CHAPTER prior to the Lecture, bring in these lecture notes and make comments on these notes. These notes alone are NOT enough to pass any test!

NOTE THESE ARE DRAFT LECTURE NOTES!

The Alchemists tried to turn Lead into Gold!

Chemistry is the **study of changes** in molecules
Nuclear Chemistry involves **changes** in the nucleus of an atom

23.1 Natural Radioactivity

Rutherford discovered the **α and β particles** in the early 1900's. Villard discovered **γ radiation** also in the early 1900's.

23.2 Equations for Nuclear Reactions

Nuclear Reactions: the natural change of an isotope of one element into an isotope of a different element.

Alpha Decay: An Alpha particle is emitted from a molecule

Radium-226 → Radon-222 + **Alpha Particle** $^{226}_{88}Ra \rightarrow {}^{222}_{86}Ra + {}^{4}_{2}\alpha$

Note: for $^{226}_{88}Ra$: 226 = sum of Protons and Neutrons or the Mass Number (A)
88 = # of Protons or the Atomic Number (Z)

	$^{226}_{88}Ra$	→	**$^{222}_{86}Ra$**	+	**$^{4}_{2}\alpha$**	
Mass Number (A):						
Protons + Neutrons	226	→	222	+	4	Decrease 4 units A
Atomic Number (Z):						
Protons	88	→	86	+	2	Decrease 2 units Z

Beta Decay: An Beta particle is emitted from a molecule

Uranium-239 → Neptunium-239 + **Beta Particle** $^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta$

Note: for $^{239}_{92}U$: 239 = sum of Protons and Neutrons or the Mass Number (A)
88 = # of Protons or the Atomic Number (Z)

	$^{239}_{92}U$	→	**$^{239}_{93}Ra$**	+	$^{0}_{-1}\beta$	
Mass Number (A):						
Protons + Neutrons	239	→	239	+	0	No Change
Atomic Number (Z):						
Protons	92	→	93	+	-1	Increase 1 units Z
How it happens:	$^{1}_{0}n$	→	$^{0}_{-1}e$	+	$^{1}_{1}p$	
	Neutron		Electron		Proton	

Radioactive Decay Series is a sequence of nuclear reactions

Uranium-238/92 decays to Thorium 234/90 and an Alpha Particle

$^{238}_{92}U \rightarrow$ $^{234}_{90}Th$ + $^{4}_{2}\alpha$ Alpha = Decrease 4 units of A, 2 of Z

Thorium 234/90 decays to Protactinium 234/91 and a Beta Particle

$^{234}_{90}Th \rightarrow$ $^{234}_{91}Pa$ + $^{0}_{-1}\beta$ Beta = No Change A, Increase 1 of Z

Protactinium 234/91 decays to Uranium-234/92 and a Beta Particle

$^{234}_{91}Pa \rightarrow$ $^{234}_{92}U$ + $^{0}_{-1}\beta$ Beta = No Change A, Increase 1 of Z

Uranium-234/92 decays to Thorium-230/90 and an Alpha Particle

$^{234}_{92}U \rightarrow$ $^{230}_{90}Th$ + $^{4}_{2}\alpha$ Alpha = Decrease 4 units of A, 2 of Z

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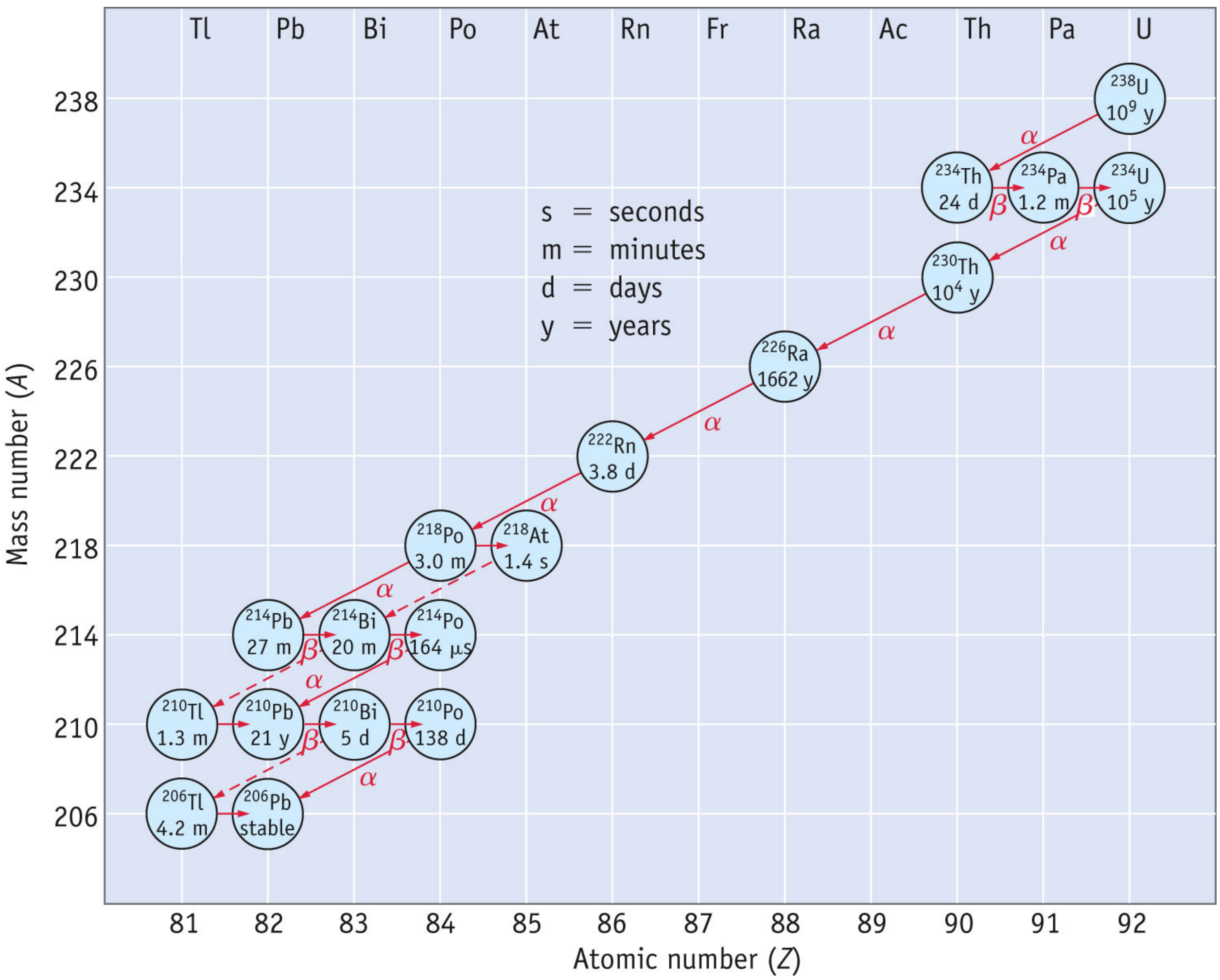
This series ends with Lead 206/82



Nuclear Particles

Name	Symbols	Charge	Mass g/particle	What is it?	Penetrate	Stop by	Net Change
Alpha	$^{4}_{2}He$ $^{4}_{2}\alpha$	2+	6.65×10^{-24}	Helium Nuclei	mm of tissue	Paper	-4 A, -2 Z
Beta	$^{0}_{-1}e$ $^{0}_{-1}\beta$	1-	9.11×10^{-28}	An Electron	Paper	0.5 cm Pb	0 A, +1 Z
Gama Radiation	γ	0	0	Electromagnetic Radiation	0.5 cm Pb	10 cm Pb	N/A
Positron	$^{0}_{+1}\beta$	+1		Antimatter Positive electron			0 A, -1 Z
Electron Capture		-1		e- + Proton = Neutron			0 A, -1 Z
Neutron Captyre	(n, γ)			Neutron captured, γ ray emitted			+1 A, 0 Z

Uranium-238's decay includes **Radon.** This is an environmental health hazard.

Radon is chemically inert, as a gas goes through cracks in your house, more dense than air so it can collect in low spots.

It is a health hazard when as its decay emits Alpha particles whose range in the body is small, but can cause damage to your lungs.

Ex 23.1 $^{235}_{92}U$ decays to $^{207}_{82}U$. How many alpha and beta particles are emitted? Write the equations for this series if the 1st three steps emit Alpha, Beta, Alpha

A: The mass (A) declines 235 – 207 = 28 mass units. 28 / 4 = 7 Alpha Particles

Atomic number (Z) declines 92 – 82 = 10.

Each Alpha Particle is a decrease of 2 for Z, or 7 * 2 = 14.

Should see a decrease of 14 for Z, but see only 10.

This is an increase of 4. Each Beta gives and increase of Z = +1

So 7 Alpha Particles 4 Beta Particles

B:

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

$^{231}_{90}Th \rightarrow\ ^{231}_{91}Pa + {}^{0}_{-1}\beta$

$^{231}_{91}Pa \rightarrow\ ^{227}_{89}Ac + {}^{4}_{2}\alpha$

Other types of Radioactive Decay

<u>Positron Emission:</u> A Positron is an electron with a + charge ${}^{0}_{+1}\beta$

The Positron is the Antimatter of an electron

Polonium 207/84 → Bismuth 207/83 + Positron 0/-1

	$\mathbf{^{207}_{84}Po}$	→	$\mathbf{^{207}_{83}Bi}$	+	${}^{0}_{+1}\beta$	
Mass Number (A):						
Protons + Neutrons	207	→	207	+	0	No change in A
Atomic Number (Z):						
Protons	84	→	83	+	+1	Decrease 1 units Z

<u>Electron Capture</u>: A extra nuclear (not from this molecule) electron is capture by the nucleus, an electron and a proton forms a neutron.

Beryllium 7/4 + Electron 0/-1 → Lithium 7/3

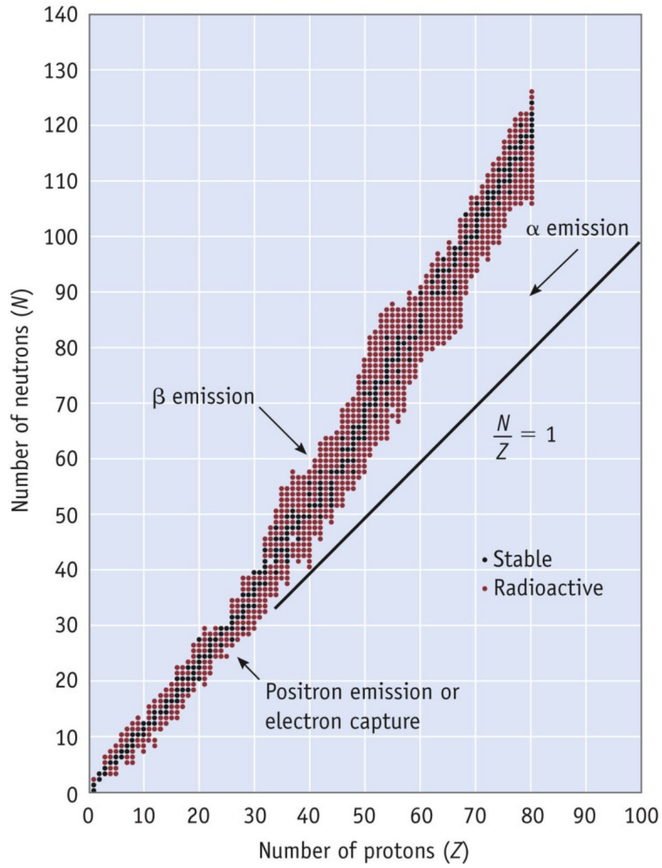
	$\mathbf{^{7}_{4}Be}$	+	${}^{0}_{-1}e$	→ $\mathbf{^{7}_{3}Li}$	
Mass Number (A):					
Protons + Neutrons	7	→	0	7	No change in A
Atomic Number (Z):					
Protons	4	→	0	3	Decrease 1 units Z

Ex 23.2 Complete the following:

$^{17}_{18}Be + {}^{0}_{-1}e \rightarrow ?$ $^{35}_{16}S \rightarrow\ ^{35}_{17}Cl + ?$

$^{11}_{6}C \rightarrow\ ^{11}_{5}B + ?$ $^{30}_{15}P \rightarrow\ ^{0}_{-1}\beta + ?$

23.3 Stability of Atomic Nuclei



- Stable isotopes fall in a narrow range called the **band of stability** (black dots)
- Only $^{1}_{1}H$ and $^{3}_{2}He$ have more protons than neutrons
- Up to Z=20, Calcium, stable isotopes have equal number of protons and neutrons, or 1 or 2 more protons
- Beyond Ca, the neutron to proton ratio > 1, getting more than > 1 as Z the number of protons increases
- Beyond Bismuth, Z=83, 126 neutrons, all isotopes are unstable and radioactive
- Isotopes that are farther from the band of stability have shorter ½ lives
- Elements with even Z have more stable isotopes then those with odd Z
- Beta emission occurs with high neutron to proton ratios, isotopes above the band of stability
- Positron emission or electron capture for low neutron to proton rations, below the band of stability

Nuclear Binding Energy is the energy required to separate the nucleus of an atom into protons and neutrons

$^{2}_{1}H \rightarrow {}^{1}_{1}p + {}^{1}_{0}n$ $\qquad E_b = 2.15 \times 108$ kJ/mol $\qquad$ Positive = energy is required.

Note: The H-H bond is only 436 kJ/mol, so the energy holding the nucleus together is 500,000 x

Mass Defect is the energy that holds the nuclear particles together. Using the Atomic Mass, the Mass Defect for Deuterium is:

$^{2}_{1}H$	$\rightarrow$	$^{1}_{1}H$	+	$^{1}_{0}n$
2.01410 g/mol		1.007825 g/mol		1.008665 g/mol

Mass Defect = Δm = mass of products - mass or reactants
= [1.007825 g/mol + 1.008665 g/mol] - 2.01410 g/mol
= 0.00239 g/mol = **2.39×10^{-6} kg/mol**

According to Albert Einstein, mass and energy are different manifestations of the same quantity

Nuclear Binding Energy = $E_b = (\Delta m)c^2$ **Δm** in Kg, **c** in meter/sec, $\boldsymbol{E_b}$ in J

For Deuterium: $\boldsymbol{E_b}$ = $(\Delta m)c^2 = (2.39 \times 10^{-6}$ kg/mol$)(2.998 \times 10^8$ m/s$)^2$
= **2.15×10^8 kJ/mol of H nuclei**

Nucleon is the binding energy/mole of nucleons = $\boldsymbol{E_b/n}$ where n = number of items in the nucleus

Deuterium contains one proton and one neutron or 2 nucleons.

$E_b/n = 2.15 \times 10^8$ kJ/ 2 = 1.08×10^8 kJ/ mole of nucleons.

The greater E_b/n, the greater the stability of the nucleus.

23.4 Rates of Nuclear Decay or half life

Half life is the time required for ½ of the sample to decay to products – 1st order kinetics

Uranium 238 $t_{1/2} = 4.47 \times 10^9$ years. The earth is 4.5×10^9 years, so half of the original U-238 is gone.

From Ch 15 $t_{1/2} = -.693 / k$ $\ln (R_t/R_o) = -kt$ -or- $R_t/R_o = e^{-kt}$

Ex 23.5 I-131 t1/2 = 8.04 days. Starting with 8.8 ug, what's left in 32.2 days?

From $t_{1/2} = -.693 / k$, $k = -.693 / t_{1/2} = 0.693 / 8.04$ day = 0.0868 / day

From $R_t/R_o = e^{-kt}$, $R_t = R_o e^{-kt}$ = 8.8 ug * e –(0.0868 / day * 32.2 days) = 8.8 ug * 16.36 * 0.0611

= 0.054 ug

Activity is the number of disintegrations observed per unit of time (you can us A in place of R above).

Radiocarbon Dating Air = Nitrogen, Oxygen and CO2 and others

Carbon 14 is ${}^{14}_{6}C$ is a ${}^{0}_{-1}\beta$ emitter with a $t_{1/2}$ = 5730 years and is formed in the upper atmosphere from Nitrogen and neutrons: ${}^{14}_{7}N$ + 10n $\rightarrow$ ${}^{14}_{6}C$ + ${}^{1}_{1}H$

${}^{14}_{6}C$ is oxidized to CO2
CO2 is absorbed by plants (photosynthesis) and converted to organic matter
This Carbon-14 CO2 is still radioactive
The Plant dies,
No more Carbon-14 CO2 is absorbed, so the existing Carbon decays, it's half-life starts
Animals eat the plants and die
We find the plants or animals thousands of years later
We measure the amount of Carbon-14 in the sample and calculate it's age
This is good for samples > 100 years and < 40,000 years old

Ex 23.7 We find a tree sample with a ^{14}C activity of 9.32 dpm/g. Ao for ^{14}C is 13.4 dm/g. t1/2 for ^{14}C is 5.73×10^3 years.

From $t_{1/2} = -.693 / k$, $k = -.693 / t_{1/2} = 0.693 / 5.73 \times 10^3$ years = 1.21×10^{-4} /year

From $\ln (R_t/R_o) = -kt$ $t = -\ln (R_t/R_o)/k = -\ln$ (9.332 dpm / 13.4 dpm) / 1.21×10^{-4} /year

= 2990 years

2010 – 2990 = 980 BC

23.5 Artificial Nuclear Reactions

Rutherford bombarded molecules with alpha particles: $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

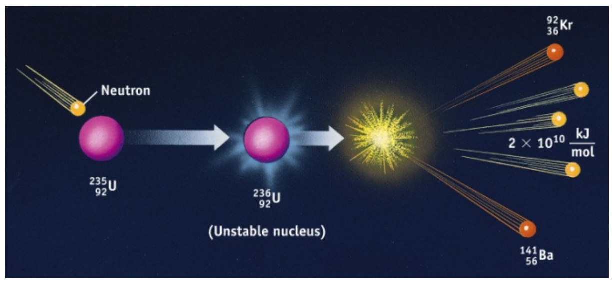
In the early 1930's particle accelerators were used to generate high energy neutrons. Remember neutrons have no charge, so it was believed that they would penetrate to the nucleus easier than the charged electron or proton!

Neutron Capture (n, γ) happens with an emitted γ ray. $^{31}_{15}P + ^{1}_{0}n \rightarrow ^{32}_{15}P + \gamma$

23.6 Nuclear Fission is where a nucleus is split into smaller pieces

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n$

Note it produces more neutrons than needed to start the reaction, this is called a Chain Reaction and how nuclear reactors work.



Cadmium rods are inserted into a nuclear reactor to absorb neutrons, as the rods are pulled out, the chain reaction starts and builds, too much and it goes into melt down as in Chernobyl or Japan.

$^{235}_{92}U$ to power reactors is generated from U-238 by centrifuging the Uranium Hexafluoride gas. The heaver gas will go to the outside of the high speed gas centrifuge. In 2010, the virus Stuxnet "May" have destroyed 1000 centrifuges in Iran. The virus sped up the centrifuges and told the operator displays that all was OK. It went boom!

23.7 Nuclear Fusion is where several small nuclei react to form a larger nucleus

Deuterium and Tritium react to form $^{4}_{2}He$ $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ $\Delta E = -1.7 \times 10^{9}$ kJ/mol

- Lots of energy is generated in these reactions
- High temperatures are needed – 10^{6} -> 10^{7} K, the temperature of plasma
- The temperature must be confined to run this reaction and generate collectable energy
- The energy must be recovered in a useable form

23.8 Radiation Health and Safety

Units for measuring Radiation

Curies	3.7×10^{10} dps (disintegrations per second)
Rad	Radiation Absorbed Dose = -.01 J of energy or the energy absorbed / kg tissue
Quality factor	Different forms of radiation cause different amounts of biological damage = 1 for $^{0}_{-1}\beta$ or γ, 5 for low energy protons, 20 for $^{4}_{2}\alpha$, high energy protons and neutrons
Rem	Roentgen Equivalent Man = Rads / Quality Factor. Milli-Rem us normally used

Effects of radiation is not generally observed below a single dose of 25 rem
A single does > 200 rem will be fatal to about ½ the population

Table 23.3 Effects of a Single Dose of Radiation

Dose (rem)	Effect
0–25	No effect observed
26–50	Small decrease in white blood cell count
51–100	Significant decrease in white blood cell count, lesions
101–200	Loss of hair, nausea
201–500	Hemorrhaging, ulcers, death in 50% of population
500	Death

Table 23.2 Radiation Exposure of an Individual for One Year from Natural and Artificial Sources

	Millirem/Year	Percentage
Natural Sources		
Cosmic radiation	50.0	25.8
The earth	47.0	24.2
Building materials	3.0	1.5
Inhaled from the air	5.0	2.6
Elements found naturally in human tissue	21.0	10.8
Subtotal	**126.0**	**64.9**
Medical Sources		
Diagnostic x-rays	50.0	25.8
Radiotherapy	10.0	5.2
Internal diagnosis	1.0	0.5
Subtotal	**61.0**	**31.5**
Other Artificial Sources		
Nuclear power industry	0.85	0.4
Luminous watch dials, TV tubes	2.0	1.0
Fallout from nuclear tests	4.0	2.1
Subtotal	**6.9**	**3.5**
Total	**193.9**	**99.9**

23.9 Application of Nuclear Chemistry

Nuclear Medicine and Medical Imaging Radioactive isotopes are used in medical diagnostic procedures

Table 23.4 Radioisotopes Used in Medical Diagnostic Procedures

Radioisotope	Half-Life (h)	Imaging
^{99m}Tc	6.0	Thyroid, brain, kidneys
^{201}Tl	73.0	Heart
^{123}I	13.2	Thyroid
^{67}Ga	78.2	Various tumors and abscesses
^{18}F	1.8	Brain, sites of metabolic activity

Space Science: Neutron Activation Analysis of the Moon Rocks
Add a neutron to a molecule, it's absorbed and emits a γ ray. The energy of the γ ray helps identify the contents of the sample.