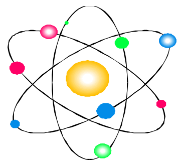
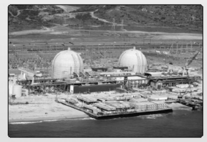
Chapter 21



Nuclear Chemistry

Nuclear Chemistry



Atomic power plants supply about 20% of the electricity generated in the United States. (Joe Azzara/Getty/The Image Bank)

A patient inhales radioactive xenon, which is taken up and carried by the bloodstream throughout the body. The helmet on the patient's head detects gamma rays from the decay, providing a visualization of blood flow in the brain. (Will and Deni McIntyre/Photo Researchers, Inc.)

Treating foods with radiation kills pathogens and makes food safer. (MDS Nordian)

A household smoke detector uses radioactive americium-241. This alpha emitter has a half-life of 470 years. In a smoke detector the emission ionizes smoke particles to activate the alarm. (Charles D. Winters)

Radioactivity

- One of the pieces of evidence for the fact that atoms are made of smaller particles came from the work of **Marie Curie** (1876-1934).
- She discovered **radioactivity**, the spontaneous disintegration of some elements into smaller pieces.

Nuclear Reactions vs. Normal Chemical Changes

- 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

Mass Defect

It is experimentally observed that the mass of an atom (containing neutrons) is always slightly less than the sum of the masses of its component particles. The difference between the atomic mass and the sum of the masses of its protons, neutrons, and electrons is called the mass defect.

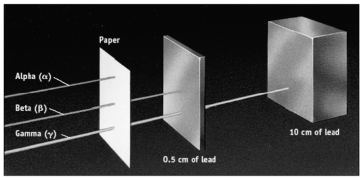
Isotope		Should Weigh:	Does Weigh:	Mass Defect:
Deuterium	1.0073 + .00055 + 1.0087 =	2.01655	2.0140	.0025
Tritium	1.0073 + .00055 + 2(1.0087) =	3.02525	3.01605	.0092

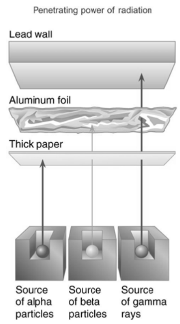
The loss in mass is accounted for by Einstein's $E = mc^2$, which describes conversions between matter (m) and energy (E). When the nucleus is being formed, some matter was converted into energy (called nuclear binding energy).

Types of Radiation

- Alpha (α) – a positively charged helium isotope - we usually ignore the charge because it involves electrons, not protons and neutrons $^{4}_{2}He$
- Beta (β) – an electron $^{0}_{-1}e$
- Gamma (γ) – pure energy; called a ray rather than a particle $^{0}_{0}\gamma$

Penetrating Ability





- Gamma rays pose the greatest external risk
- Alpha pose the greatest risk if emitted from ingested radioactive particles

Nuclear Reactions

Like a typical chemical reaction, where:

A + B → C + D

Nuclear Reactions are written with the elements, plus the Atomic Number & Atomic Mass for each participant.

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

But is it Balanced???

Balancing Nuclear Reactions

1. **In the reactants (starting materials – on the left side of an equation) and products (final products – on the right side of an equation)**

   Atomic numbers must balance
   and
   Mass numbers must balance

2. **Use a particle or isotope to fill in the missing protons and neutrons**

Natural Nuclear Reactions

- Radioactivity that occurs NATURALLY, without human intervention, or cause.

Natural Nuclear Reactions

- Alpha Emission

	$^{226}_{88}Ra$	$\longrightarrow$	$^{4}_{2}\alpha$	+	$^{222}_{86}Rn$
	radium-226	$\longrightarrow$	α particle	+	radon-222
Mass number: (protons + neutrons)	226	=	4	+	222
Atomic number: (protons)	88	=	2	+	86

Note that mass number (A) goes down by 4 and atomic number (Z) goes down by 2.

Nucleons (nuclear particles… protons and neutrons) are rearranged but conserved

Natural Nuclear Reactions

- Beta Emission

	$^{239}_{92}U$	$\longrightarrow$	$^{0}_{-1}\beta$	+	$^{239}_{93}Np$
	uranium-239	$\longrightarrow$	β particle	+	neptunium-239
Mass number: (protons + neutrons)	239	=	0	+	239
Atomic number: (protons)	92	=	−1	+	93

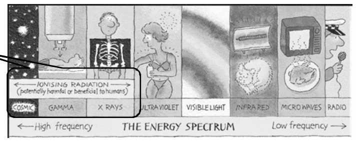
Note that mass number (A) is unchanged and atomic number (Z) goes up by 1.

Natural Nuclear Reactions

Gamma Radiation $^{0}_{0}\gamma$

- Type of high energy radiation that has no mass or charge

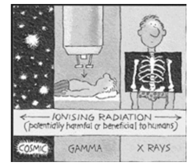
Ionizing Radiation: Can change molecule or atoms into ions



- Very dangerous: can only be stopped by thick lead

Ionizing vs. Non-Ionizing Radiation

Ionizing Radiation: Radiation has sufficient Energy to change molecule or atoms into ions



Non-Ionizing Radiation: Cannot change molecules or atoms into ions … too weak.

Other Nuclear Particles

- Neutron $^{1}_{0}n$
- Positron – a positive electron $^{0}_{+1}e$
- Proton – usually referred to as hydrogen-1 $^{1}_{1}H$

The "Must-Know" Nuclear Particles

- Alpha (α): $^{4}_{2}He$
- Beta (β): $^{0}_{-1}e$
- Gamma (γ): $^{0}_{0}\gamma$
- Neutron: $^{1}_{0}n$
- Positron: $^{0}_{+1}e$
- Proton : $^{1}_{1}H$

Other Types of Natural Nuclear Reactions

Positron ($^{0}_{+1}\beta$): a positive electron

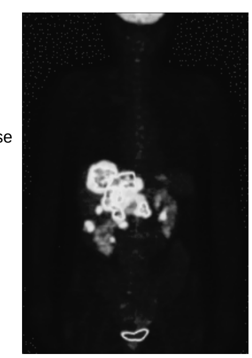
	$^{207}_{84}Po$	$\longrightarrow$	$^{0}_{+1}\beta$	+	$^{207}_{83}Bi$
	polonium-207	$\longrightarrow$	positron	+	bismuth-207
Mass number: (protons + neutrons)	207	=	0	+	207
Atomic number: (protons)	84	=	+1	+	83

Electron capture: the capture of an electron

	$^{7}_{4}Be$	+	$^{0}_{-1}e$	$\longrightarrow$	$^{7}_{3}Li$
	beryllium-7	+	electron	$\longrightarrow$	lithium-7
Mass number: (protons + neutrons)	7	+	0	=	7
Atomic number: (protons)	4	+	−1	=	3

Positron Emission Tomography (PET) Scanning

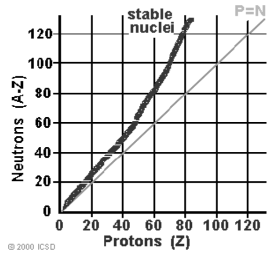
- A Positron Emitter is attached to Glucose, and injected into the body.
- Cancerous Tissue uses more Glucose than Normal Tissue, and appears brighter in the PET Scan



$$^{18}_{9}F \rightarrow {}^{0}_{+1}e + {}^{18}_{8}O$$

What makes a nucleus unstable?

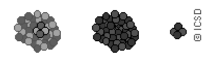
- Stability comes from the ratio of neutrons to protons
- Radioactive decay is an attempt to 'correct' the ratio of neutrons to protons
- Elements with atomic # above 83 are all radioactive



GHS Honors Chem

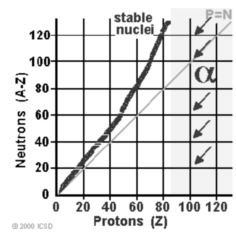
What makes a nucleus unstable?

Alpha Decay



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

92 p^+	90 p^+
146 n	144 n



- Happens to nuclei with Z>83
- The 2 p+ 2n loss brings the atom down and to the left toward the belt of stable nuclei.

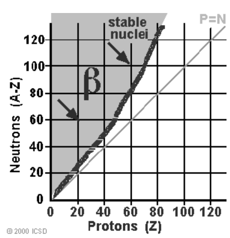
GHS Honors Chem

What makes a nucleus unstable?

Beta Decay

$^{131}_{53}I \rightarrow\ ^{131}_{54}Xe +\ ^{0}_{-1}e$

53 p^+	54 p^+
78 n	77 n



- Happens to nuclei with high neutron/proton ratio
- Causes a shift down and to the right on the stability graph

GHS Honors Chem

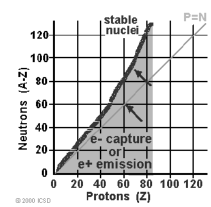
What makes a nucleus unstable?

Electron Capture or Positron Emission

$^{81}_{37}Rb +\ ^{0}_{-1}e \rightarrow\ ^{81}_{36}Kr$

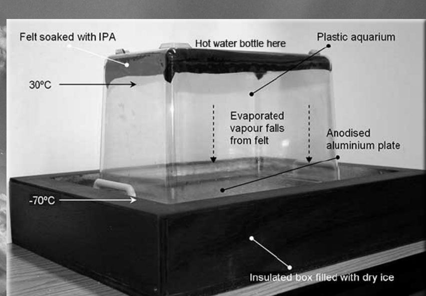
$^{11}_{6}C \rightarrow\ ^{11}_{5}B +\ ^{0}_{1}e$

Happens to nuclei with a low neutron/proton ratio



GHS Honors Chem

The Cloud Chamber



GHS Honors Chem

Artificial Nuclear Reactions

- **Radioactivity that is produced by bombarding, or striking, a nucleus with a subatomic particle, or another atom.**
- **The Radioactivity would otherwise NOT occur naturally.**

GHS Honors Chem

Artificial Nuclear Reactions

Example of a γ reaction is production of radioactive ^{31}P for use in studies of P uptake in the body.

$$^{31}_{15}P + ^{1}_{0}n \text{ ---> } ^{32}_{15}P + \gamma$$

GHS Honors Chem

Transuranium Elements

- Transuranium elements are those elements with Atomic Numbers above 92.
- Elements beyond 92 *(transuranium)* are made starting with an γ reaction

$^{238}_{92}U + ^{1}_{0}n \text{ ---> } ^{239}_{92}U + \gamma$

$^{239}_{92}U \text{ ---> } ^{239}_{93}Np + ^{0}_{-1}\beta$

$^{239}_{93}Np \text{ ---> } ^{239}_{94}Pu + ^{0}_{-1}\beta$

GHS Honors Chem

Learning Check

What radioactive isotope is produced in the following bombardment of boron?

$$^{10}_{5}B + ^{4}_{2}He \longrightarrow ? + ^{1}_{0}n$$

GHS Honors Chem

Learning Check: Writing Nuclear Equations

Write the nuclear equation for the beta emission from Co-60.

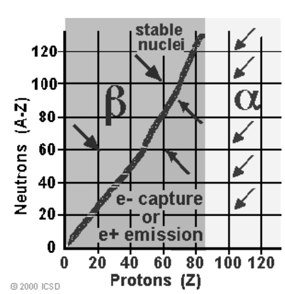
GHS Honors Chem

LC: Writing Nuclear Equations

Uranium-235 is bombarded with 1 neutron in an artificial transmutation. Krypton-92 and Barium-140 are released, as well as some neutrons. How many neutrons are released?

GHS Honors Chem

The Drive Towards Stability



Let's take a Quick Quiz to see what you've learned ....

GHS Honors Chem

Nuclear Chemistry Worksheet

GHS Honors Chem