22 • Nuclear Chemistry
The People
(1 of 16)

- **Wilhelm Roentgen** (1845-1923) discovered X-rays, a high energy form of light. (1895)
- **Henri Becquerel** (1852-1909) found that uranium ores emit radiation that can pass through objects (like x-rays) and affect photographic plates. (1896)
- **Marie Sklodowska Curie** (1867-1934) Marie and Pierre worked with Becquerel to understand radioactivity. The three shared a Nobel Prize in Physics in 1903. Marie won a second Nobel Prize in Chemistry in 1911 for her work with radium and its properties.
- **E. O. Lawrence** invented the cyclotron which was used at UC Berkeley to make many of the transuranium elements.

---

22 • Nuclear Chemistry
Terms I-- Radioactivity
(2 of 16)

radioactivity	the spontaneous breakdown of atomic nuclei, accompanied by the release of some form of radiation (also called **radioactive decay**)
half-life	time required for half of a radioactive sample to decay
transmutation	one element being converted into another by a nuclear change
nuclides	isotopes of elements that are identified by the number of their protons and neutrons

---

22 • Nuclear Chemistry
Terms II--Radioactivity
(3 of 16)

decay series	the sequence of nuclides that an element changes into until it forms a stable nucleus
radioactive dating	using half-life information to determine the age of objects. C-14/C-12 is common for organic artifacts. Uranium is common for rocks.
nuclear fission	large nucleus breaking down into pieces of about the same mass
nuclear fusion	two or more light nuclei blend to form one or more larger nuclei

---

22 • Nuclear Chemistry
Types of Radiation
(4 of 16)

Alpha particles are the same as a helium nucleus, ${}^{4}_{2}\text{He}$, with a mass of 4 amu. It travels about 1/10th the speed of light and is the most easily stopped of the three particles (a sheet of paper will stop them). It is the least dangerous.

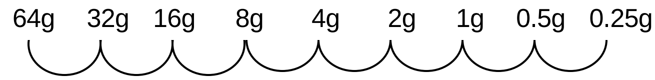
Beta particles are high speed electrons, ${}^{0}_{-1}\text{e}$, with a mass of 0.00055 amu and travel at nearly the speed of light. They can be stopped by a sheet of aluminum. It is more penetrating and therefore more dangerous than alpha.

Gamma rays are extremely high energy light, γ, with no mass, and are the most penetrating (several cm's of lead are needed to stop them). They can cause severe damage.

22 • Nuclear Chemistry
Half-Life Problems
(5 of 16)

In each half-life problem there are basically <u>four</u> variables:

- total time
- starting amount
- half-life
- ending amount



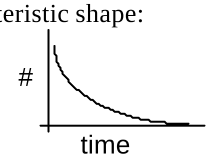
Question:
If you have 0.25 g of a radioactive substance with a half life of 3 days, how long ago did you have 64 grams?

Answer: Draw the chart to determine the number of half-lives to get from the ending amount to the starting amount… each half-life is worth 3 days…**24 days**.

22 • Nuclear Chemistry
Half-Life
(6 of 16)

Half-Life The time it takes for half of a radioactive substance to decay.

The decay graph has a characteristic shape:



The time it takes for the **amount** of substance or the **activity** of the substance to drop to half is the same WHEREVER you start on the graph. This is a first-order reaction.
Half-lives can range from microseconds to thousands of years and is characteristic of each substance.

22 • Nuclear Chemistry
Nuclear Equations
(7 of 16)

Memorize the symbols for the important particles

<u>**alpha**</u>	<u>**beta**</u>	<u>**positron**</u>	<u>**neutron**</u>
${}^{4}_{2}\mathrm{He}$	${}^{0}_{-1}\mathrm{e}$	${}^{0}_{+1}\mathrm{e}$	${}^{1}_{0}\mathrm{n}$

Decay means the particle is on the right side of the equation:
example: **alpha** decay of U-**238**

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

The 234 and 90 are calculated… the Th is found on the periodic table (find the element with atomic # = 90).
Several neutrons can be shown together and written as…

$3({}^{1}_{0}\mathrm{n})$ and would be counted as ${}^{3}_{0}\mathrm{n}$ in the equation.

22 • Nuclear Chemistry
How Each Type of Decay Can Stabilize an Unstable Nucleus
(8 of 16)

Certain values of p^{+}'s and n°'s in the nucleus are stable. A nucleus can be unstable (radioactive) for 3 reasons:

• the nucleus has **too many protons** compared to neutrons
solution: **positron** decay
(change a proton into a neutron and a positive electron… …a positron)

• the nucleus has **too many neutrons** compared to protons
solution: **beta** decay
(change a neutron into a proton and a negative beta particle)

• the nucleus is **too big** (too many protons <u>and</u> neutrons)
solution: **alpha** decay (lose 2 p^{+} and 2 n°)

22 • Nuclear Chemistry
Uses of Radioactivity
(9 of 16)

Radioactive Dating: In every living thing there is a constant ratio of normal C-12 and radioactive C-14. You can calculate the time needed to change from what is expected to what is actually found.

Radioisotopes: Many substances can be radioactive and then followed as they move through the body.

Fission Reactors: Current nuclear reactors use fission reactions to produce heat which is used to turn water into steam and drive turbine engines that produce electricity.

The Sun and Stars are powered by nuclear fusion… this is related to the fact that the most abundant element in the universe is hydrogen… followed by helium.

---

22 • Nuclear Chemistry
Fission and Fusion Reactions
(10 of 16)

U-235 is "**fissionable**" which means it can be split when bombarded by neutrons.

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

The fact that each splitting nucleus can emit neutrons that can split other nuclei is the basis for the "chain reaction." **"Breeder reactors"** use different isotopes.

Fusion in the Sun involves several steps that can be summed up as: $4(^{1}_{1}H) \rightarrow ^{4}_{2}He + 2^{0}_{1}e + \text{energy}$

Thermonuclear devices use isotopes of hydrogen (deuterium and tritium): $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$

---

22 • Nuclear Chemistry
Energy–Mass Conversions
(11 of 16)

Einstein's famous equation, $\mathbf{E = mc^2}$, is the basis for explaining where the energy associated with nuclear changes comes from.

When a nuclear change occurs, the mass of the products is slightly less than the mass of the reactants. This loss in mass is called the **mass defect.**

E = the energy
m = the mass defect
c = the speed of light, 3.00×10^8 m/s

1 kg of mass converted into energy would be equivalent to burning **3 billion kg of coal!**

---

22 • Nuclear Chemistry
What Happens During Beta and Positron Decay
(12 of 16)

During **beta decay**,
1 neutron changes into 1 proton + 1 negative beta particle
(The atomic # increases by one due to the new proton. The mass # is unchanged… a neutron is gone. To maintain electrical neutrality, a negative beta particle is also formed.)

Example: $^{235}_{92}U \rightarrow ^{0}_{-1}e + ^{235}_{93}Np$

During **positron decay**,
1 proton changes into 1 neutron + 1 positron particle
(The atomic # decreases by one due to the loss of a proton. Since it changed into a neutron, the mass # is unchanged.)

Example: $^{235}_{92}U \rightarrow ^{0}_{+1}e + ^{235}_{91}Pa$

22 • Nuclear Chemistry
Calculating Half-Lives
(13 of 16)

When a problem involves **whole numbers** of half-lives, divide by 2 to determine the amounts involved.
For other situations, the following **equations** are useful:

$\ln \frac{[A]_0}{[A]_t} = kt$ and the special case for half-life, $t_{1/2}$ where by definition, $[A]_t = ½[A]_0$ $\ln 2 = 0.693 = kt_{1/2}$

[A] is the concentration (or activity) of the radioactive substance, t = time, k = the rate constant (the same that is in Rate Laws). Note: if you know the half-life, you can calculate the rate constant and vice-versa.

22 • Nuclear Chemistry
Radioactive Decay Series
(14 of 16)

Once a nucleus decays, the **daughter** isotope is often unstable as well. **Many decays** may occur before a **stable** nucleus is formed.

A classic example is **U-238** that decays through 14 steps into stable Pb-206. Each step has a characteristic decay particle and half-life.

This **characteristic decay series** is the method used to verify the identity of newly formed atoms.

The fact that daughter products can be even more radioactive than the parent isotope adds to the problem of **nuclear waste** and its storage/disposal.

22 • Nuclear Chemistry
Geiger-Muller Tubes, Smoke Detectors, and Brushes for Cleaning Negatives
(15 of 16)

An useful characteristic of decay particles are that they **ionize the air** they pass through by striking atoms and knocking off electrons.

Geiger counters use this idea. As radioactive particles pass through a chamber with two electrodes, ionized particles migrate to the + and - electrodes and complete the circuit.

Smoke Detectors use a tiny piece of radioactive Am to keep a circuit flowing due to ionized particles. Smoke particles attract ionized particles, break the circuit, & set off the alarm.

Brushes are kept ionized by tiny bits of radioactive material to more easily attract tiny bits of dust.

22 • Nuclear Chemistry
Extending the Periodic Table
(16 of 16)

Uranium, Z=92, is the largest naturally-occurring element. Larger atoms were manufactured. Elements 93 and 94 were formed in atomic bomb tests and identified by Seaborg. **Glenn Seaborg** and **Al Ghiorso** at UC Berkeley were able to use E. O. Lawrence's cyclotron to make larger atoms (95-103).

Some of these new elements have uses in the medical field as well as helping to further the understanding of the nucleus. For many of the larger elements, however, only a few atoms or even one atom formed. They were identified by their characteristic decay series.

As of July 2000, **118** is the largest element.