Chemistry 104 Chapter Eleven PowerPoint Notes

Nuclear Chemistry
Chapter 11

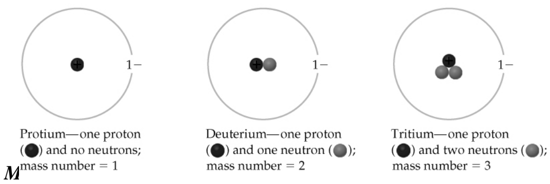
Chemistry 104
Professor Michael Russell

Chapter 3 Flashback - Isotopes

Isotopes are atoms with identical atomic numbers (Z) but different mass numbers (A)

Protium, deuterium, and tritium are isotopes of hydrogen:

- Protium: one proton (Z=1) and no neutrons (A=1)
- Deuterium: one proton (Z=1) and one neutron (A=2)



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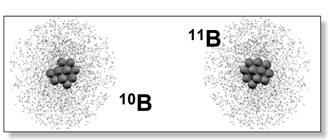
Isotopes Review

Atoms of the same element (same Z) but different mass number (A).

Boron-10 has 5 p and 5 n: ${}^{10}_{5}B$

Boron-11 has 5 p and 6 n: ${}^{11}_{5}B$



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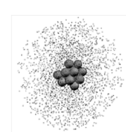
Nuclear Reactions

A ***nucleon*** is a general term for both protons and neutrons.

Atoms with identical atomic numbers but different mass numbers are known as ***isotopes***, and the nucleus of a specific isotope is known as a ***nuclide***.

A ***Nuclear Reaction*** is a reaction that changes the atomic nucleus, usually causing the change of one element into another.



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Nuclear reactions change an atom's nucleus, usually producing a different element.

Chemical reactions never change the nucleus, they only rearranges the outer shell electrons.

Different isotopes of an element have essentially the same behavior in chemical reactions but often have completely different behavior in nuclear reactions.

Example: ^{238}U is not very reactive

Example: ^{235}U used in atomic bombs; very reactive

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The ***rate*** (or speed) of nuclear reaction is not affected by a change in temperature, pressure, etc.

Atomic nuclear reactions essentially the same whether active species is a chemical compound or an element.

The energy change accompanying a nuclear reaction can be several million times greater than the energy change accompanying a chemical reaction.

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The Discovery of Nature of Radioactivity

Radioactivity is the spontaneous emission of radiation from a nucleus.

Henry Becquerel, a French physicist, discovered radioactivity in 1896.

Becquerel placed a sample of uranium-containing mineral on top of a photographic plate wrapped in black paper. On developing the plate, Becquerel found a silhouette of the mineral on the plate.

He concluded some kind of energy was emitted by the mineral that passed through the paper to expose the photographic plate.

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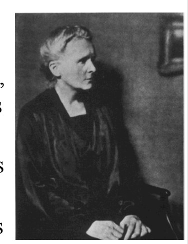
Marie Curie and her husband **Pierre** studied this phenomenon and termed **radioactivity.**

Types of radioactivity:

- Alpha (α): a helium nucleus, He^{2+}, with two protons and two neutrons is emitted
- Beta (β); a supercharged electron is emitted
- Gamma, (γ); high-energy light waves are emitted; massless



Marie Curie

Radiation comes from the nucleus (not the electrons) and is difficult to detect without instruments

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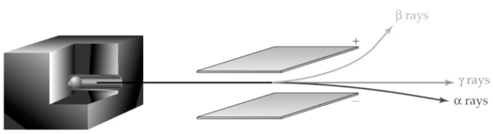
Detection of radiation through charged plates: opposites attract, like repels

Alpha (+) radiation is deflected toward the negative plate.

Beta (-) radiation is deflected toward the positive plate.

Gamma radiation is not deflected - no charge.



Effect of an electric field on alpha, beta, gamma radiation

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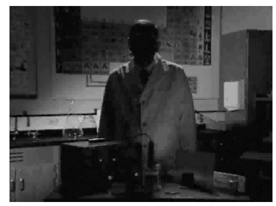
Radioactive Particles

Each particle has different properties



Alpha **- stopped by clothes**
Beta **- stopped by skin**
Gamma **- stopped by lead**

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Stable and Unstable Isotopes

Every element in the periodic table has at least one radioactive isotope.

Radiation is emitted when an unstable radioactive nucleus spontaneously changes into a more stable isotope.

For the elements up to Calcium (Z=20), stability is associated with a roughly equal number of neutrons and protons.

Past Ca and up to Bismuth (Bi, Z=83), stable elements require more neutrons than protons.

Past Bismuth, all isotopes radioactive

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Balancing Nuclear Reactions

*** Number of *reactant* protons must equal the number of *product* protons**

*** Number of *reactant* neutrons must equal the number of *product* neutrons**

Example:

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

A: 226 = 4 + 222
Z: 88 = 2 + 86

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Nuclear Decay

The spontaneous emission of a small particle from an unstable nucleus is called ***nuclear decay*** or ***radioactive decay.***

Atoms of one element can change into atoms of another element through radioactive decay – phenomena known as ***transmutation.***

Many ***decay modes*** possible: alpha emission, beta emission, gamma emission, positron emission and electron capture

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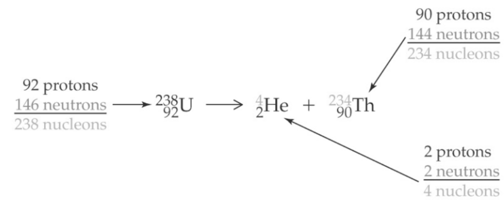
Alpha emission: When an atom emits an alpha particle, the nucleus loses two protons and two neutrons. An example of an alpha emission:



Emission of an alpha particle from an atom of uranium-238 produces an atom of thorium-234.

Notice how atomic and mass numbers constant

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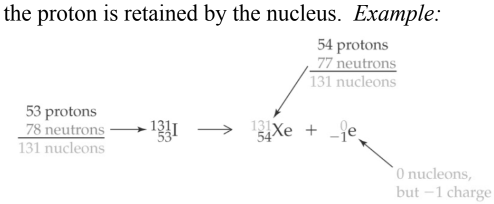
Beta emission: Beta emission leads to the decomposition of a neutron to yield an electron and a proton. The electron is ejected as a beta particle and the proton is retained by the nucleus. *Example:*



Emission of a beta particle from an atom of iodine-131 produces an atom of xenon-131.

Notice how *total* atomic and mass numbers constant

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Gamma emission: Emission of gamma rays causes no change in the mass or atomic number because gamma rays are simply high energy electromagnetic waves.

Their penetration power makes them the most dangerous kind of radiation for humans but also beneficial (Cobalt-60 used in cancer therapy)

$$^{11}_{5}B^{*} \longrightarrow {}^{11}_{5}B + \gamma$$

Gamma ray

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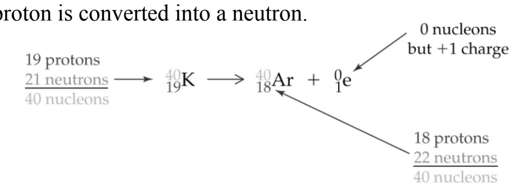
Positron emission: Positron emission involves conversion of a proton in the nucleus into a neutron *plus* an ejected ***positron*** or β^+. A positron has the same mass as an electron but a positive charge. Result of positron emission is a decreases in the atomic number of the product nucleus since a proton is converted into a neutron.



Emission of a positron from an atom of potassium-40 produces an atom of argon-40.

Notice how *total* atomic and mass numbers constant

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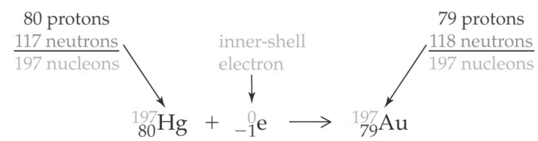
Electron capture **(E.C.)** is a process whereby nucleus captures an inner-shell electron, converting a proton into a neutron. The mass number of the product nucleus remains the same, but the atomic number decreases by one as in positron emission.



Capture of an electron by an atom of mercury-197 produces an atom of gold-197.

Notice how *total* atomic and mass numbers constant

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Balancing Nuclear Reactions

Problem: Uranium-235 decomposes through beta decay to a new product. Find the identity of the new product.

Solution:

Uranium has 92 protons, so: $^{235}_{92}U$

Beta decay **means "losing a beta particle", or generating a beta particle as a product, so:**

$$^{235}_{92}U \longrightarrow ^{0}_{-1}e + ^{A}_{Z}X$$

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Balancing Nuclear Reactions

Problem: Uranium-235 decomposes through beta decay to a new product. Find the identity of the new product.

$$^{235}_{92}U \longrightarrow ^{0}_{-1}e + ^{A}_{Z}X$$

Solution:

235 = 0 + A, therefore A = 235
92 = -1 + Z, therefore Z = 93
If Z = 93, X = Neptunium (Np), and

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

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Test Yourself

Problem: Radon-222 decomposes through alpha decay to a new product. Find the identity of the new product.

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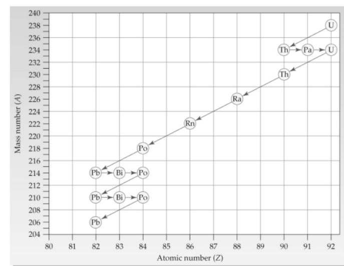
Radioactive Decay Series

A **Decay Series** shows a sequential series of nuclear disintegrations (decay processes) leading from a heavy, unstable radioisotope to a non-radioactive product.



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Radioactive Half-Life

A **half life** ($t_{1/2}$) is defined as *the amount of time required for one half of the radioactive sample to decay*.

The rate of radioactive decay varies greatly from one isotope to another.

Example: ^{17}C $t_{1/2}$ = 0.0011 s *(fast)*

Example: ^{235}U $t_{1/2}$ = 7.038 * 10^8 years *(slow)*

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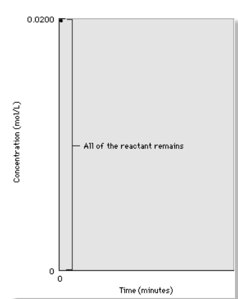

Half-Life

In beginning we have 0.0200 mol H_2O_2.

Half life ($t_{1/2}$) for H_2O_2 is 654 minutes.

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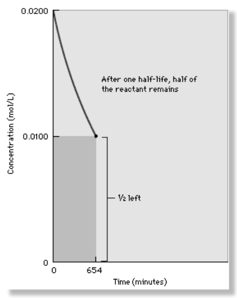

Half-Life

Reaction after 654 min, 1 half-life.

1/2 of the reactant remains.

Since we started with 0.0200 mol H_2O_2, we now have 0.0100 mol remaining.

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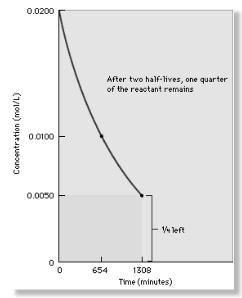

Half-Life

Reaction after 1308 min, or 2 half-lives.

1/4 of the reactant remains.

Since we started with 0.0200 mol H_2O_2, we now have 0.0050 mol remaining.

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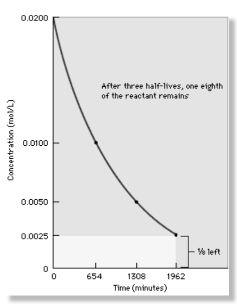

Half-Life

Reaction after 3 half-lives, or 1962 min.

1/8 of the reactant remains.

Since we started with 0.0200 mol H_2O_2, we now have 0.0025 mol remaining.

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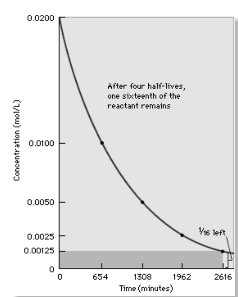

Half-Life

Reaction after 4 half-lives, or 2616 min.

1/16 of the reactant remains.

Since we started with 0.0200 mol H_2O_2, we now have 0.00125 mol remaining.

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Example: Half-Life

15 mg of ^{99}Tc is administered to a patient. How much is left in the body after 12 hours if the half-life of Tc, $t_{1/2}$, is equal to 6.0 hours?

Solution:

Realize that 12 hours is equal to 2 half-life.

Thus,

$$15\text{ mg} \xrightarrow{6\text{ hrs}} 7.5\text{ mg} \xrightarrow{6\text{ hrs}} 3.75\text{ mg}$$

1st half-life **2nd half-life**

9.29

Test Yourself

Problem: A sugar fermentation process has a half life of 35 minutes. If you start with 10.00 g of sugar, how much is left after 2 hours and 20 minutes?

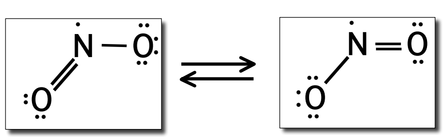
9.30

Free Radicals

Free radicals contain unpaired electrons (NO_2)

Can be created through radiation

Responsible for aging, cancer, food spoilage, much more



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Fusion

Tremendous amounts of energy are generated when light nuclei combine to form heavier nuclei - nuclear fusion

$${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n \quad \Delta E = -1.7*10^{9}\text{ kJ/mol}$$

"Clean" energy, used in stars and bombs, requires *plasma* and/or high temperatures

No "meltdown" - reaction just stops, no waste

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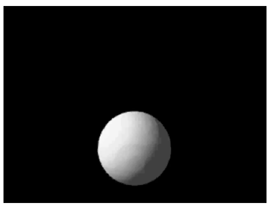
Fission

Tremendous amounts of energy also generated when heavy nuclei split to form lighter nuclei - *nuclear fission*

Generally requires a "neutron trigger"



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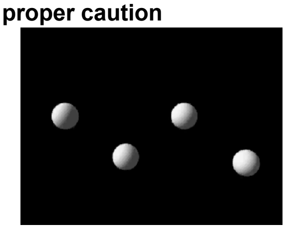
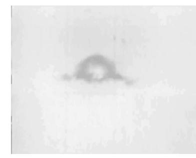
Fission

Excess neutrons *must* be controlled!

Supercritical chain reactions can result without proper caution





Waste products from fission messy and virtually perpetual

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Radiation and Health

Some radiation is all around us all of the time

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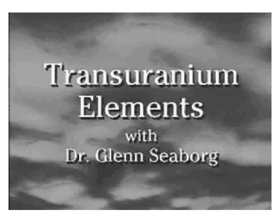
Uses for Nuclear Chemistry

Expands the frontier of science



Dr. Glenn Seaborg (1912 - 1999)

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Uses for Nuclear Chemistry
Radiocarbon Dating

$t_{1/2}$ = 5730 years for carbon-14
Accurate up to 60,000 years old!

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Uses for Nuclear Chemistry
Energy

Fission most important commercially (so far!), but fusion is coming!

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Uses for Nuclear Chemistry
Medicine

PET and MRI most common, but many more applications exist

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End of Chapter 11

To review and study for Chapter 11, look at the "Concepts to Remember" at the end of Chapter Eleven