6.5 - Nuclear Reactions & Stability

Nuclear Structure Review

Nuclei consist of positive protons (p^+) (the atomic number) and neutral neutrons (^1_0n in reactions).

Sum of nucleons is the mass number.

The short-range strong nuclear force holds nucleons together, and is the strongest force in the universe (besides love).

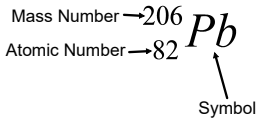
Isotopic Notation

Elements are defined by atomic number; neutron count varies.

Atoms of the same element with differing neutrons are called isotopes.

Element-mass number notation: Lead-206 or Pb-206.

Isotope notation:



0. Isotope Practice

Calculating nucleons in isotopes is important.

A. How many protons, neutrons, and electrons are in the following neutrally charged uranium isotope?

$^{238}_{92}U$

Protons and Electrons = 92
Neutrons = mass number - atomic number = 146

B. What's the mass # of an isotope of phosphorus with 19 neutrons (use periodic table resource P. 21)?
Mass number = protons + neutrons = 15 + 19 = 34.

Nuclear Reactions

If a nucleus decays into another atom, a balancing process is used:

Mass numbers & atomic numbers of parents, daughters, and particles must be equal on both sides of the reaction.

$$^{22}_{10}Parent \rightarrow {}^{12}_{6}Daughter\,1 + {}^{9}_{4}Daughter\,2 + {}^{1}_{0}n$$

Alpha Particle (Symbol: α)

With two neutrons and two protons, it is a helium–4 (He-4) nucleus: when it slows down, it captures two electrons and becomes helium.

It can be stopped by paper, and has + 2 charge.

In reactions, it's shown thusly: ^4_2He or $^4_2\alpha$.

α (alpha particle) = ^4_2He

1. Alpha Decay Example

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

This reads: radium-226 decays into radon-222 and an alpha particle.

1. You do! What's the parent isotope?

$$? \longrightarrow {}^{251}_{98}Cf + {}^{4}_{2}He$$

$^{255}_{100}$**Fm**

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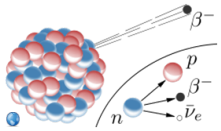
Beta Particles (Symbol: β^-)

Are fast-moving electrons produced during neutron decay, and can be stopped by or a few pieces of aluminum foil. The reaction symbol is: ${}^{0}_{-1}e$

What actually happens: a neutron spontaneously changes to a proton if the neutron : proton ratio is too high, ejecting an electron and a neutrino (an even smaller particle).



$${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

Beta Decay Examples

Fill in the missing parents or daughters in the following nuclear equations:

2. $?? \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

${}^{14}_{6}C$

3. ${}^{48}_{18}\text{Ar} \longrightarrow \quad ? \quad + {}^{0}_{-1}\text{e}$

${}^{48}_{19}\text{K}$

Positron Emission (Symbol: β^+)

When an atom has too many protons compared to neutrons, a *positron* (positive electron) can form, generating a neutron.

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

This is a type of antimatter: when a positron meets an electron, the pair is annihilated, producing two gamma rays. "Pure energy", as Spock would say.

4. Complete the reaction.

$${}^{15}_{8}O \rightarrow \quad ?? \quad + {}^{0}_{+1}e$$

$$?? \; = {}^{15}_{7}N$$

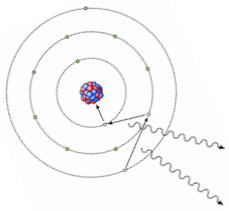
Electron Capture (Abbreviation: EC)

Occasionally, in an atom with an abundance of protons vs. neutrons, an electron in an inner orbital will be absorbed by a proton and form a neutron.

$${}^{1}_{1}p + {}^{0}_{-1}e \rightarrow {}^{1}_{0}n$$

This only happens if the nucleus lacks the energy to undergo positron emission.

Electrons emit X-Rays as they replace the absorbed one.



Ex: 5.

$${}^{81}_{36}Kr + {}^{0}_{-1}e \rightarrow ?? \qquad ?? = {}^{81}_{35}Br$$

Gamma Ray (Symbol: γ)

Photon (no mass or charge) <u>usually accompanying</u> another decay. Stopped by thick lead or concrete.

6. Determine the daughter product.

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

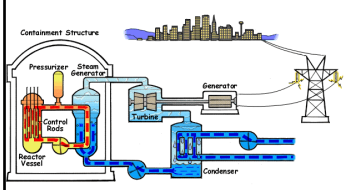
Sometimes an unstable nucleus (symbol: *) self-reacts, making a gamma ray as nucleons 'shift' to a more stable configuration:

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

Fission

An isotope undergoes decay to form daughter elements: often triggered by neutron bombardment.

In nuclear reactors, <u>fissile</u> materials heat up as they decay, boiling water that turns a steam-driven turbine.



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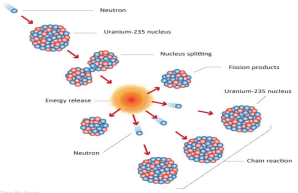
Fission Example

7. What's the missing daughter product?

$^{238}_{92}U + {}^{1}_{0}n \rightarrow ?? + {}^{92}_{36}Kr + 3\left({}^{1}_{0}n\right)$ **Answer:** $^{144}_{56}Ba$

The production of neutrons can lead to a chain reaction, whether controlled or uncontrolled.



Fusion

Lighter elements combine at high temperatures or pressures.

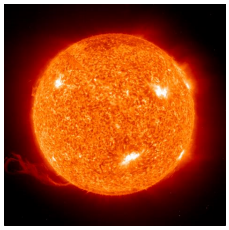
This is used in hydrogen bombs, (not in a power generating capacity yet).

Hydrogen forms helium in a series of steps:

$$^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{+1}e$$

$$^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma$$

$$^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2({}^{1}_{1}H)$$



Health Effects

Which type of radiation (alpha, beta, gamma) damages living beings most?

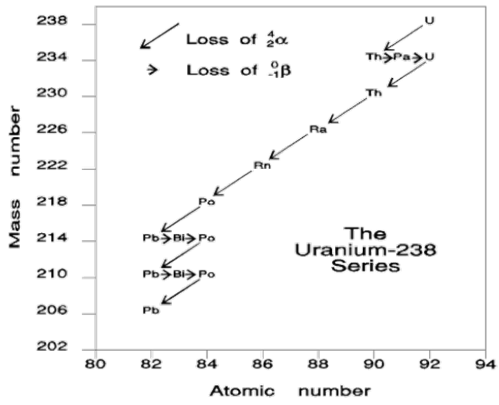
Gamma rays penetrate deeper into a body, but alpha particles have quite a punch when they hit.

Radiation weakens structural materials.

Nuclear Stability

Unstable isotopes decay until they are stable.

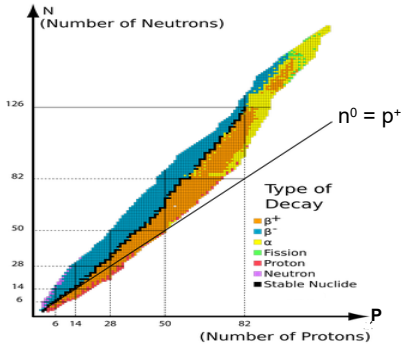
Uranium-238 becomes Lead-206:



Nuclear Stability

Ratio of neutrons to protons determines stability.

Stable isotopes form after enough decay occurs.



General Stability Rules

1. Isotopes with atomic number > 83 are unstable. Strong nuclear force works at short range: beyond a certain distance proton repulsion tears nucleus apart.

2. Proton:Neutron pairing effects:
   a. Most even:even nuclei are stable.
   b. Many odd:even and even:odd nuclei are stable.
   c. Only four odd:odd nuclei are stable:

$^{2}_{1}H$ $^{6}_{3}Li$ $^{10}_{5}B$ $^{14}_{7}N$

3. a. Stable nuclei with mass numbers < 40 have about the same numbers of protons and neutrons.
   b. Stable nuclei with mass numbers > 40 have more neutrons than protons.

Homework 6.5
Problems 6.5 in your Booklet
Due: Next Class