Nuclear Chemistry

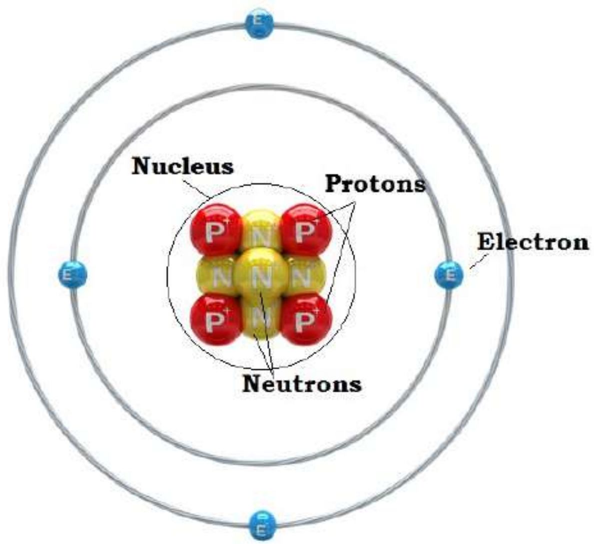
Chemistry
Unit 5
Module 4

Module Concepts

- Nuclear Chemistry
- Isotope Stability
- Radioactive Decay
  - Alpha
  - Beta
  - Gamma
  - Positron
  - Electron Capture
- Half Life Calculations

Nuclear chemistry

- Changes the NUCLEUS
- Turns one element into a different element!

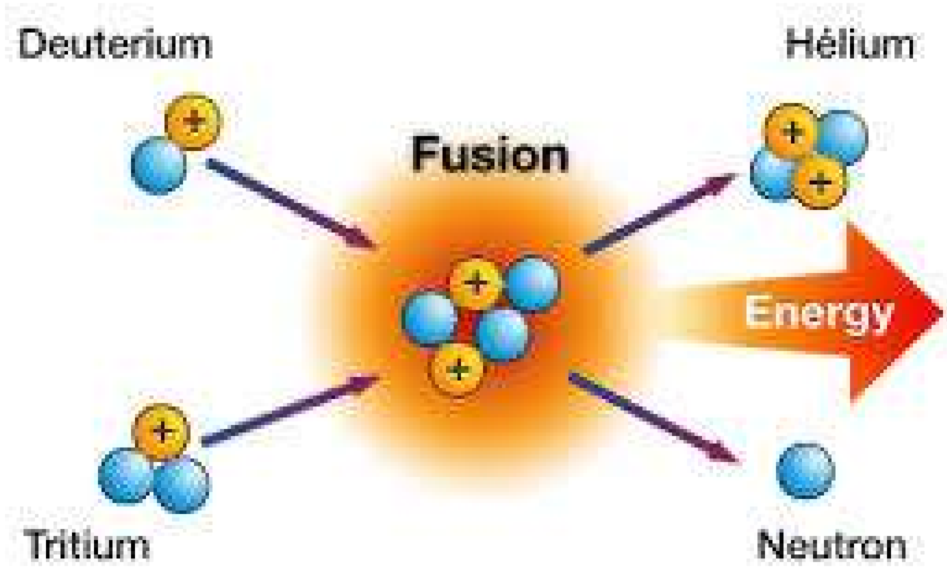


Chemical reactions change electrons

Nuclear reactions change protons/neutrons

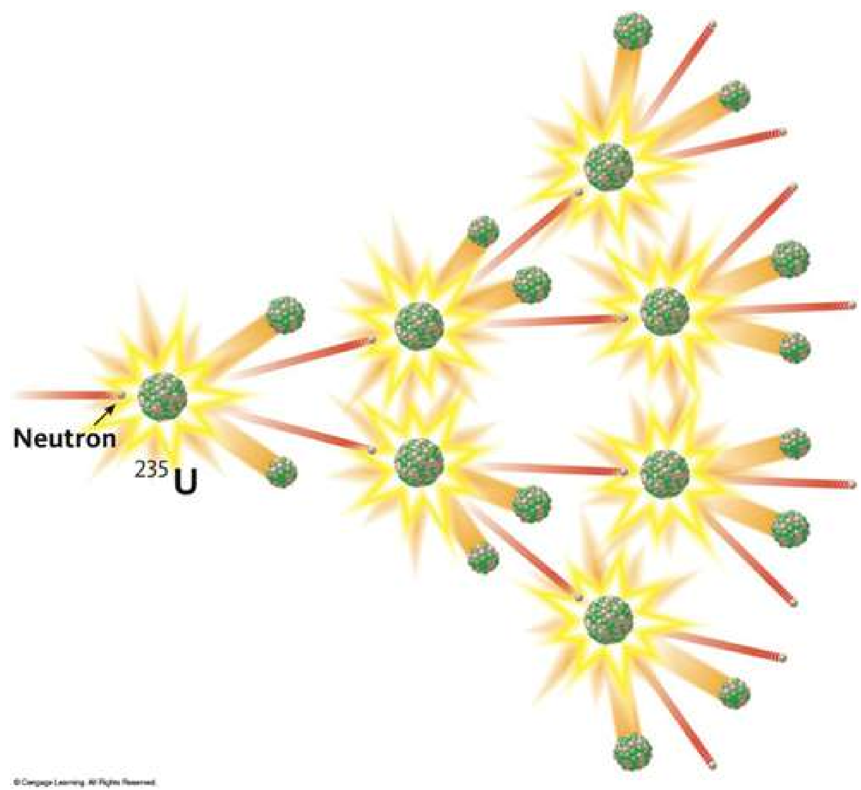
Fusion

Two or more atoms are smashed together and their nuclei combine



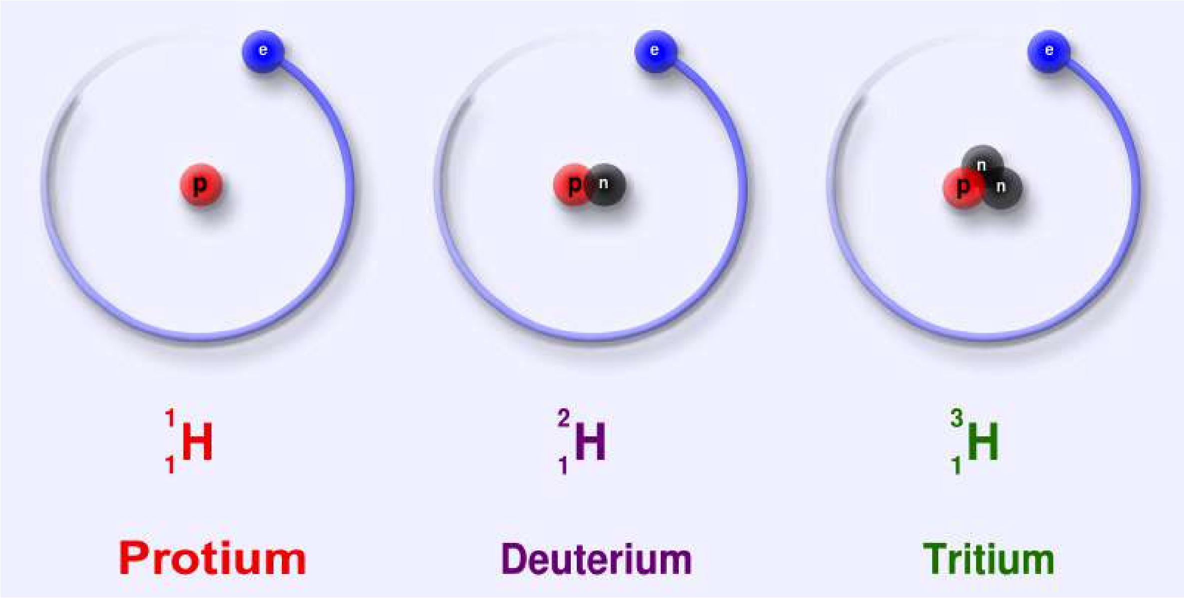
Fission

- An unstable nucleus is hit by a small fast particle (usually a neutron), which breaks it apart into multiple big atoms
- Some nuclei can react in more than one way
- Usually releases more neutrons, which causes a chain reaction



Element Stability

- Not all isotopes of a given element are stable.
  - Example: Hydrogen has three isotopes, H – 1 (protium), H – 2 (deuterium), and H – 3 (tritium). Protium and deuterium are stable, but tritium is not. What is different about these three isotopes that might account for the difference in stability?



Element Stability

- The stability of a given atom is dependent on the ratio of protons to neutrons.

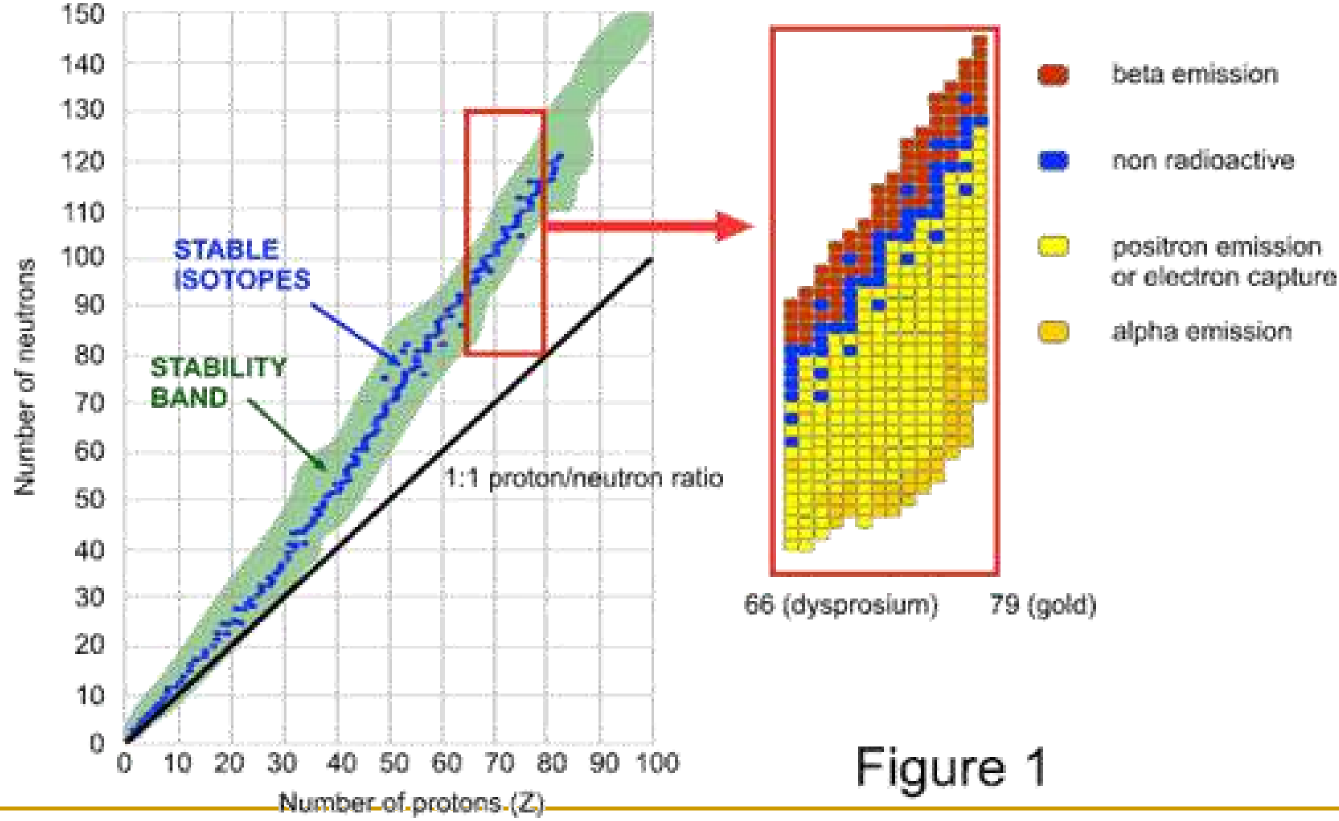
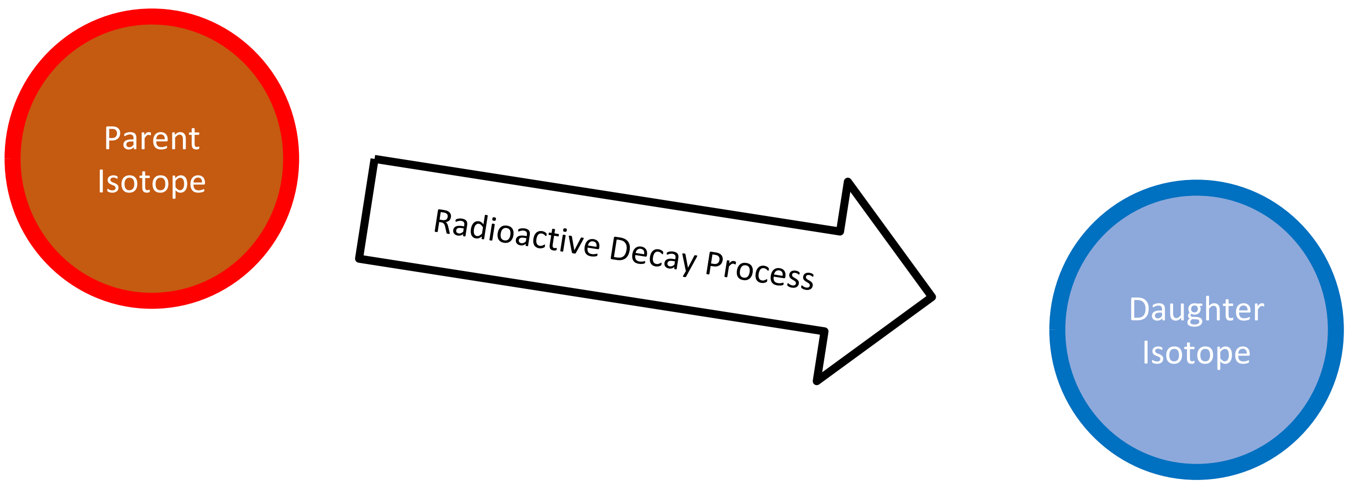


Figure 1

Radioactive Decay

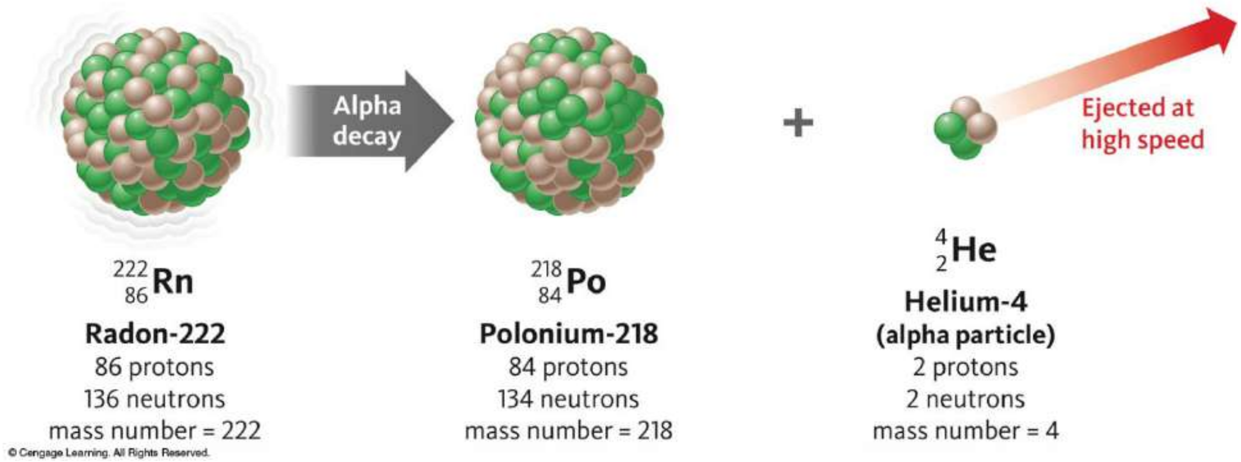
- Spontaneous disintegration of an unstable nucleus (parent isotope) into a lighter and more stable nucleus (daughter isotope) by the emission of small particles and energy



- There are several types of radioactive decay

Alpha Decay

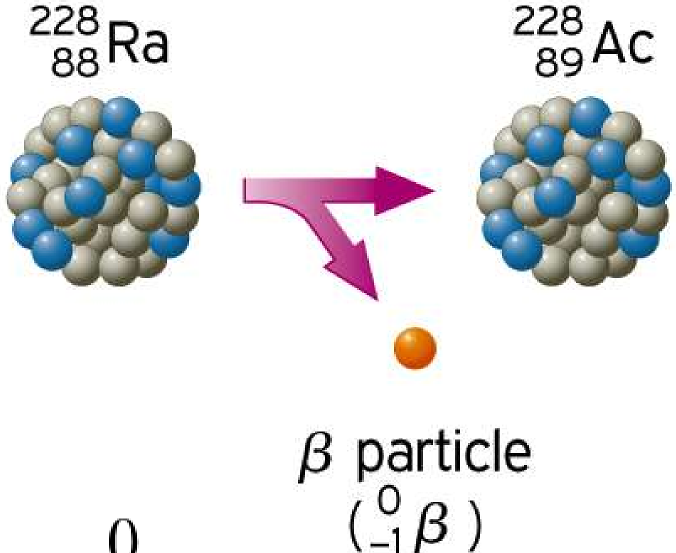
- Alpha particles contain 2 protons and 2 neutrons (they are equivalent to Helium nuclei) and have a 2+ charge and a mass number of 4



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

Beta Decay

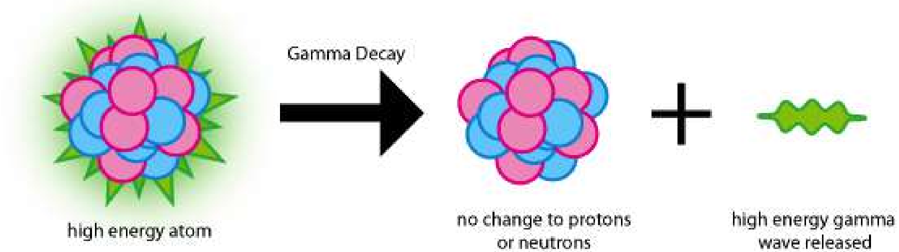
- Beta radiation, β or Beta particles are electrons (no mass) and have a 1- charge, but a mass of zero

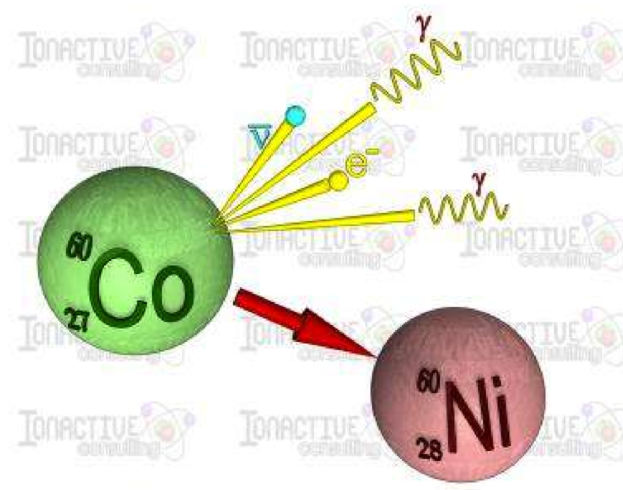


$$^{131}_{53}I \rightarrow ^{131}_{54}Xe + ^{0}_{-1}e$$

Gamma Decay

- Gamma radiation, γ
  - Gamma rays are high-energy radiation that have no mass. Gamma rays are frequently emitted in conjunction with other forms of radioactive decay.





Positron Emission

Some nuclei decay by emitting a **positron**, a particle that has the same mass as, but an opposite charge to, that of an electron:

$$ {}^{0}_{1}e $$

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

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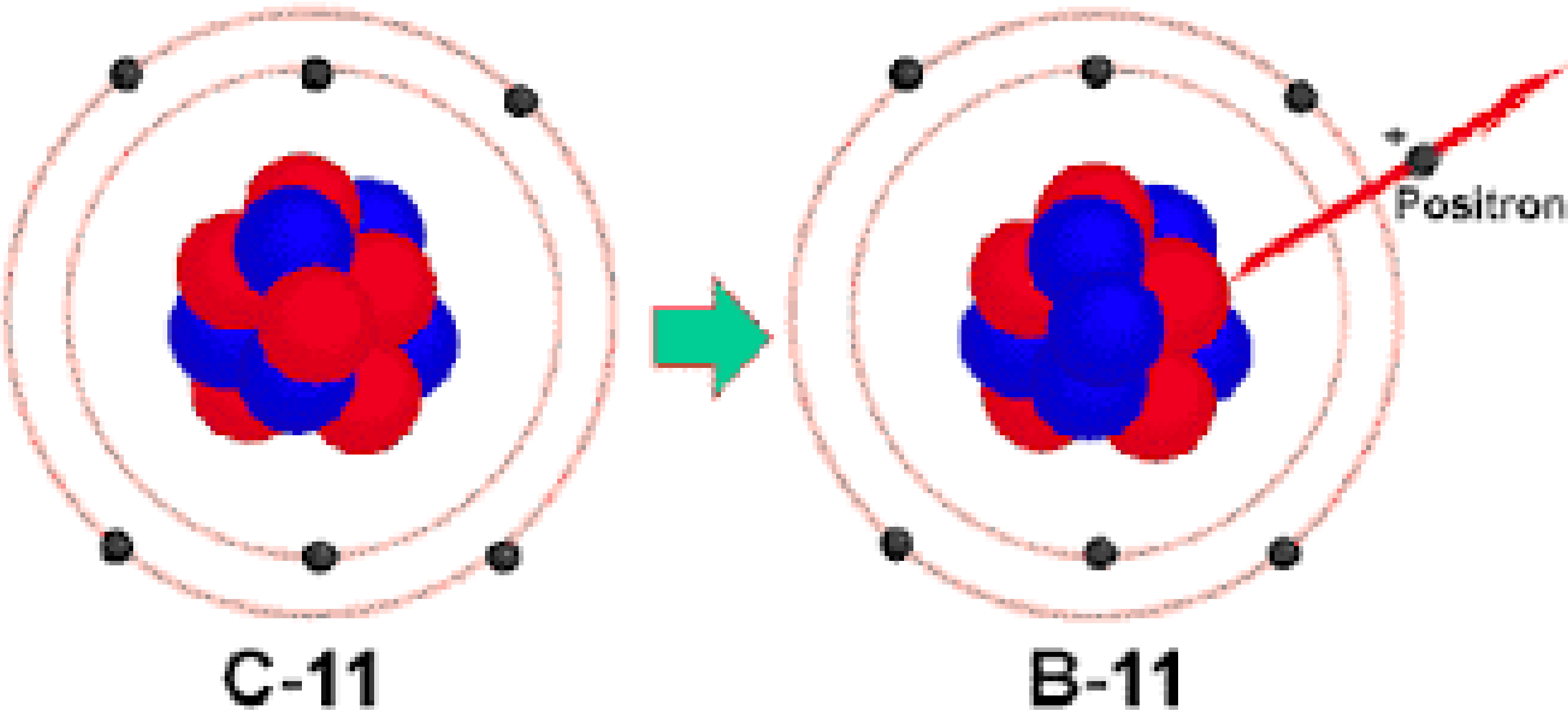
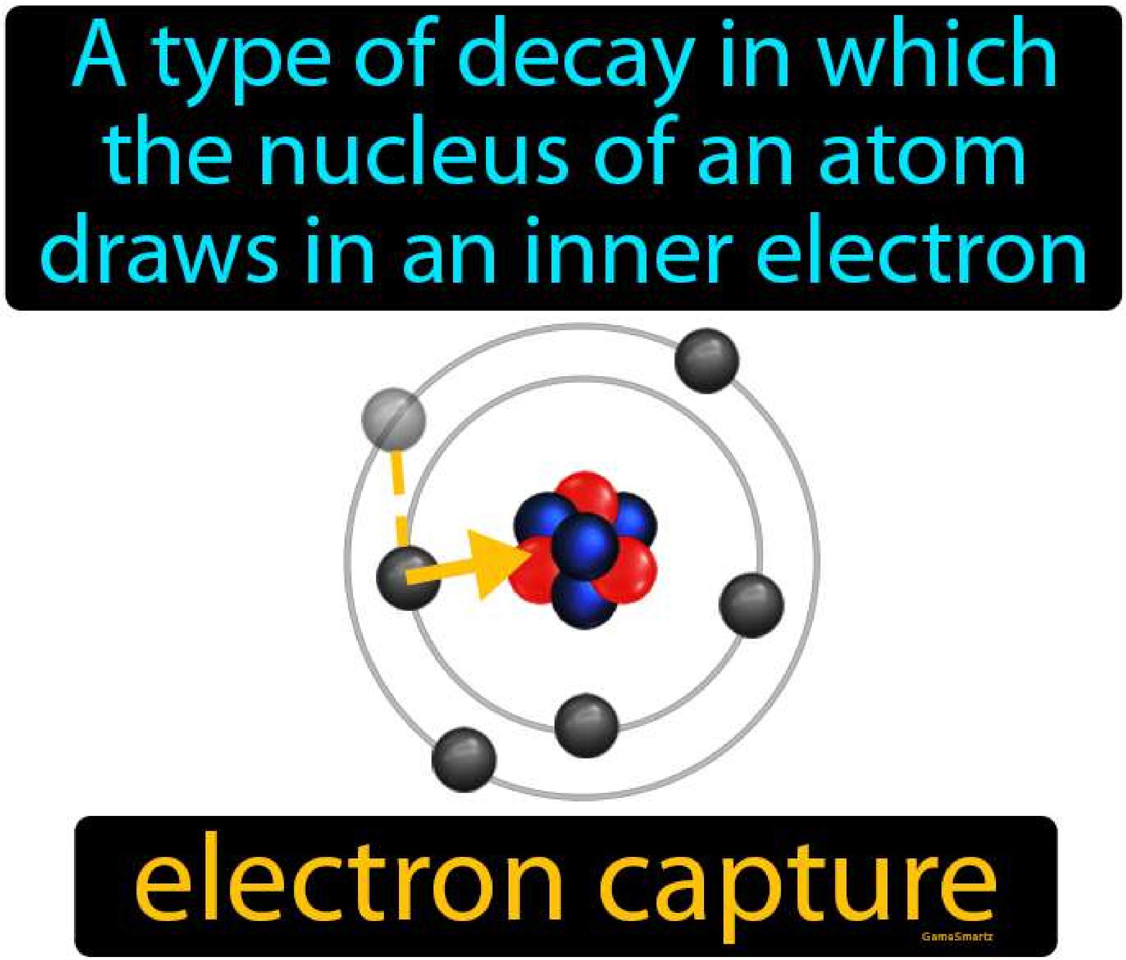
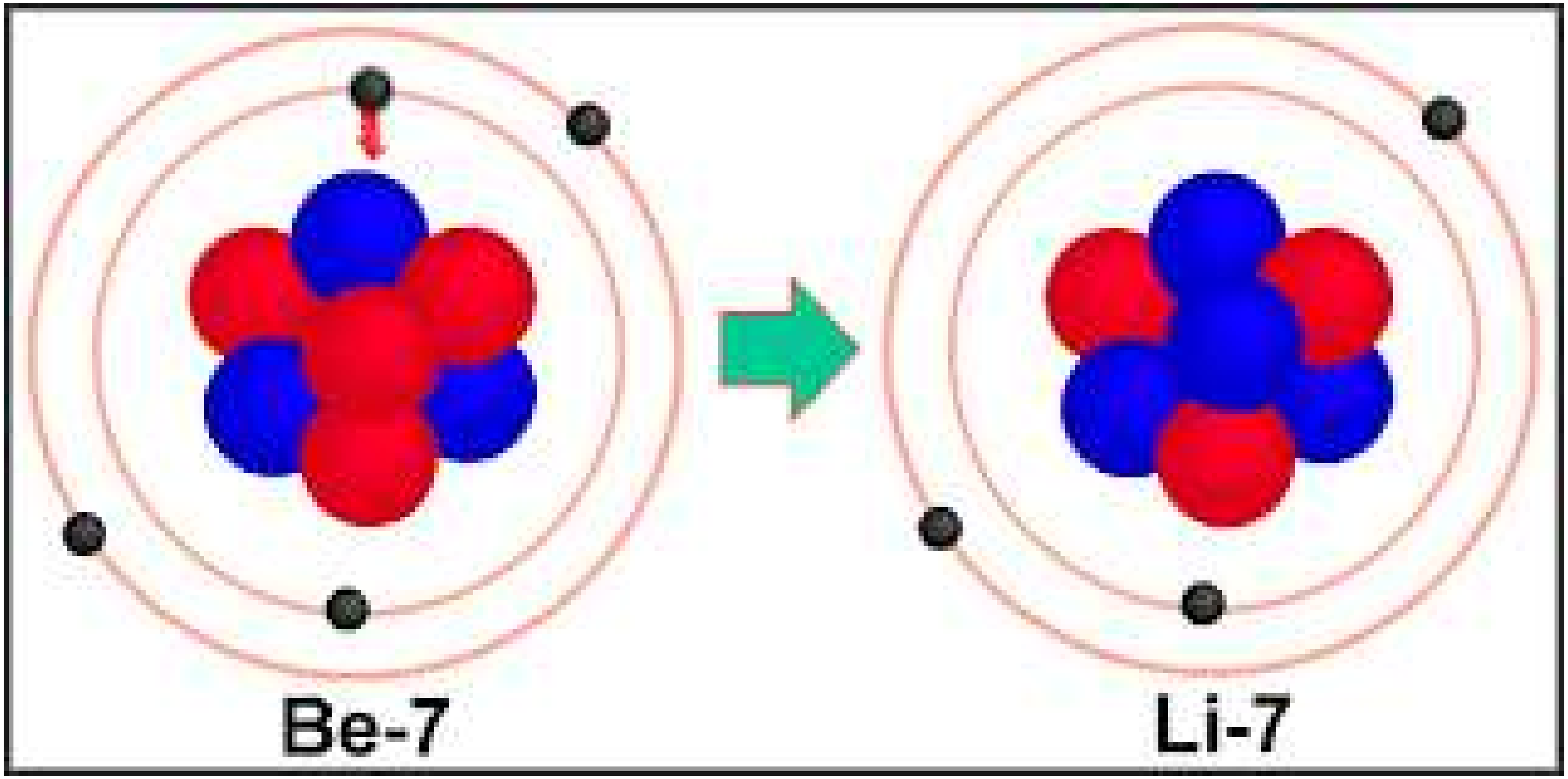


+
Positron
C-11
B-11

Electron Capture



Electron Capture



$${}^{7}_{4}Be + {}^{0}_{-1}e \rightarrow {}^{7}_{3}Li$$

Balancing Nuclear Equations

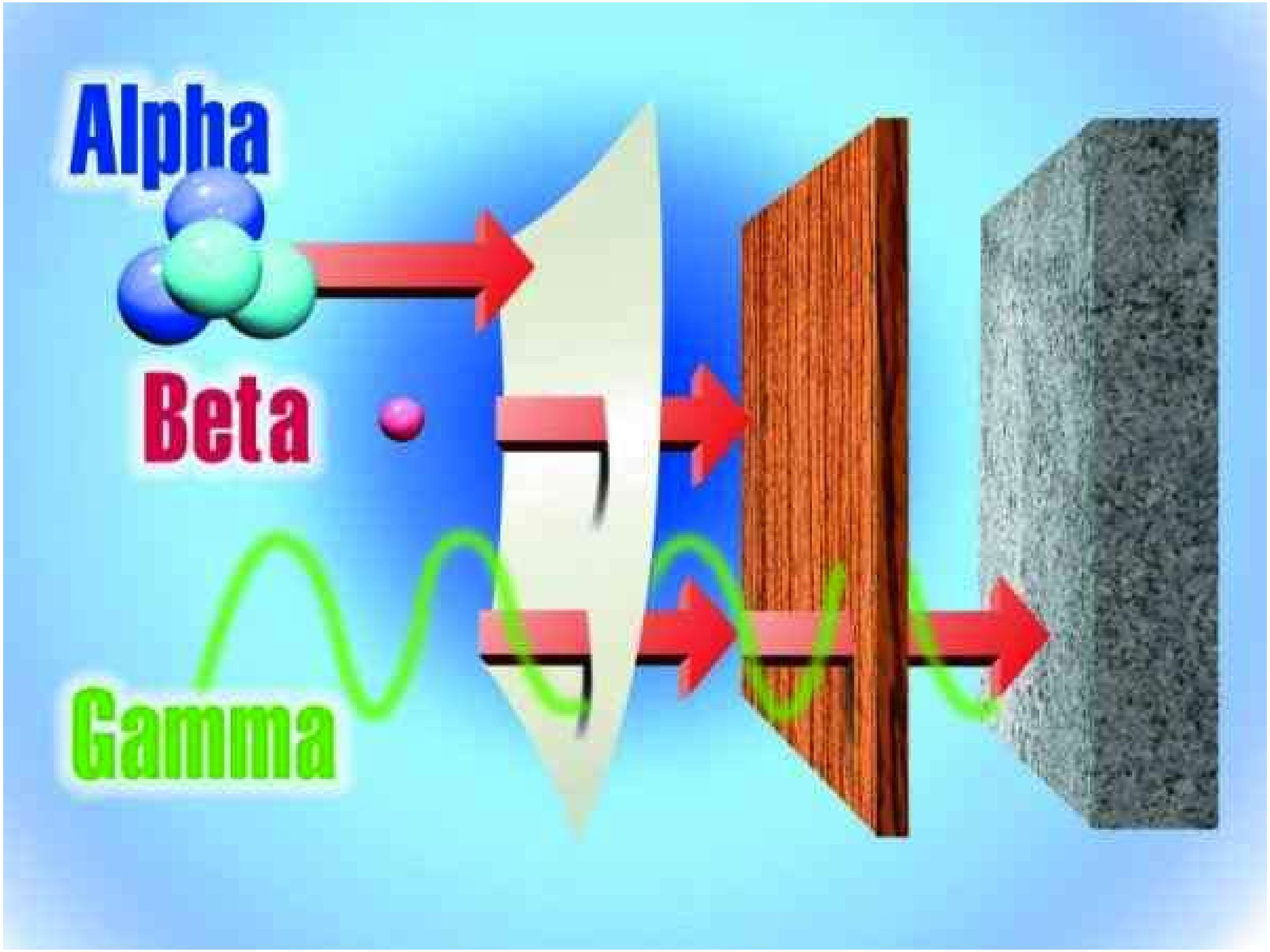
- Mass and Charge must be conserved
- So…
  - The sum of the mass numbers (the top number in notation) and
  - The sum of the atomic numbers (the bottom number in notation, equivalent to charge)
- are the SAME on both sides of an equation

Nuclear Equations

$$^{230}_{90}\mathrm{Th} \longrightarrow {}^{0}_{-1}e + ?$$

Radioactive Decay Particles - Comparison

- Radiation is harmful to the human body. How do these radioactive decay particles compare in terms of the danger they present to humans?
- The greater the penetrating ability of the radioactive decay particle, the more dangerous the particle is to humans.
- How do we measure penetrating ability? By comparing the thickness of the substance required to "stop" the particle from moving forward.

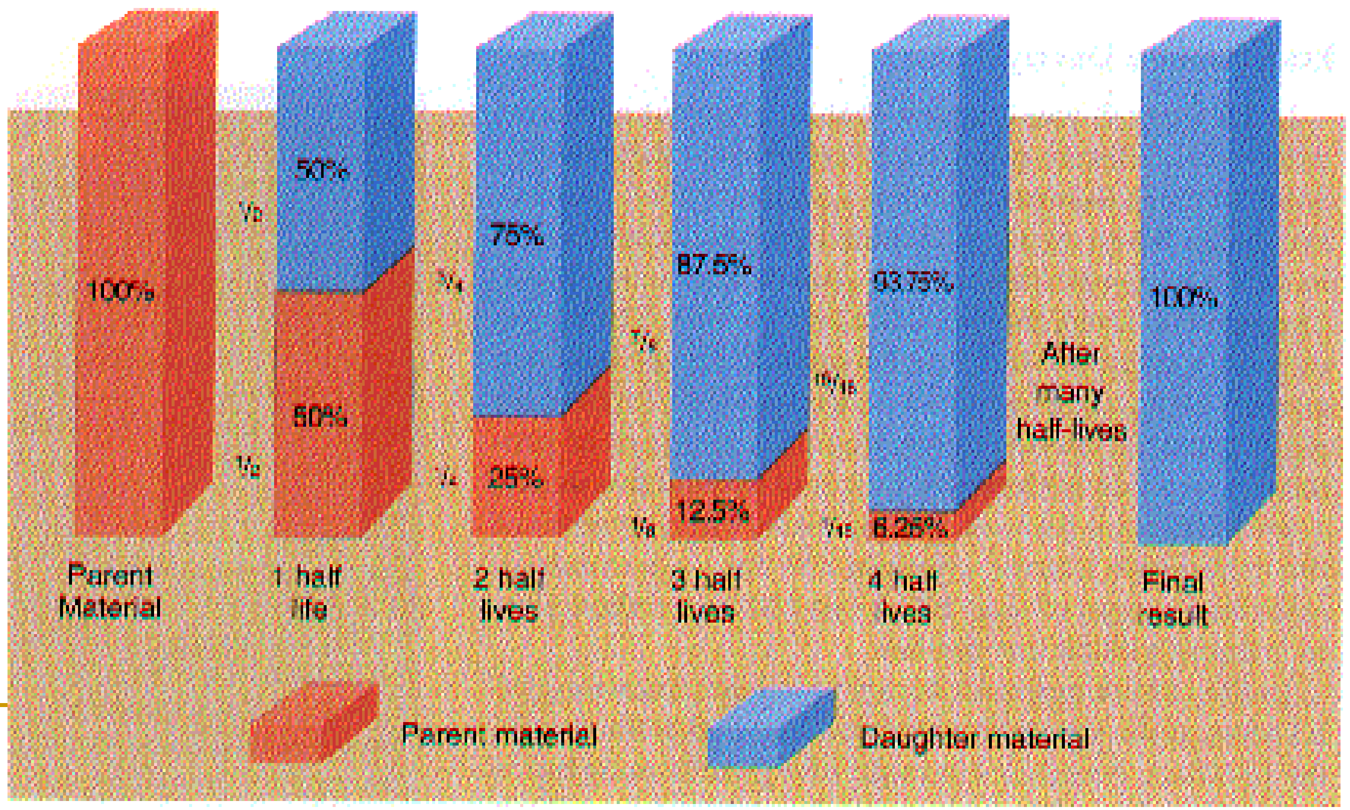

Alpha
Beta
Gamma

Comparing Radioactive Decay

- Conclusion? Gamma radiation is the most dangerous type of decay since it can only be stopped by something thick like lead, followed by beta decay. Alpha decay particles are the least dangerous form of radioactive decay since they can be stopped by something thin, like a sheet of paper or material.

Half Life

The time required for 1/2 of a parent material to break down to daughter material

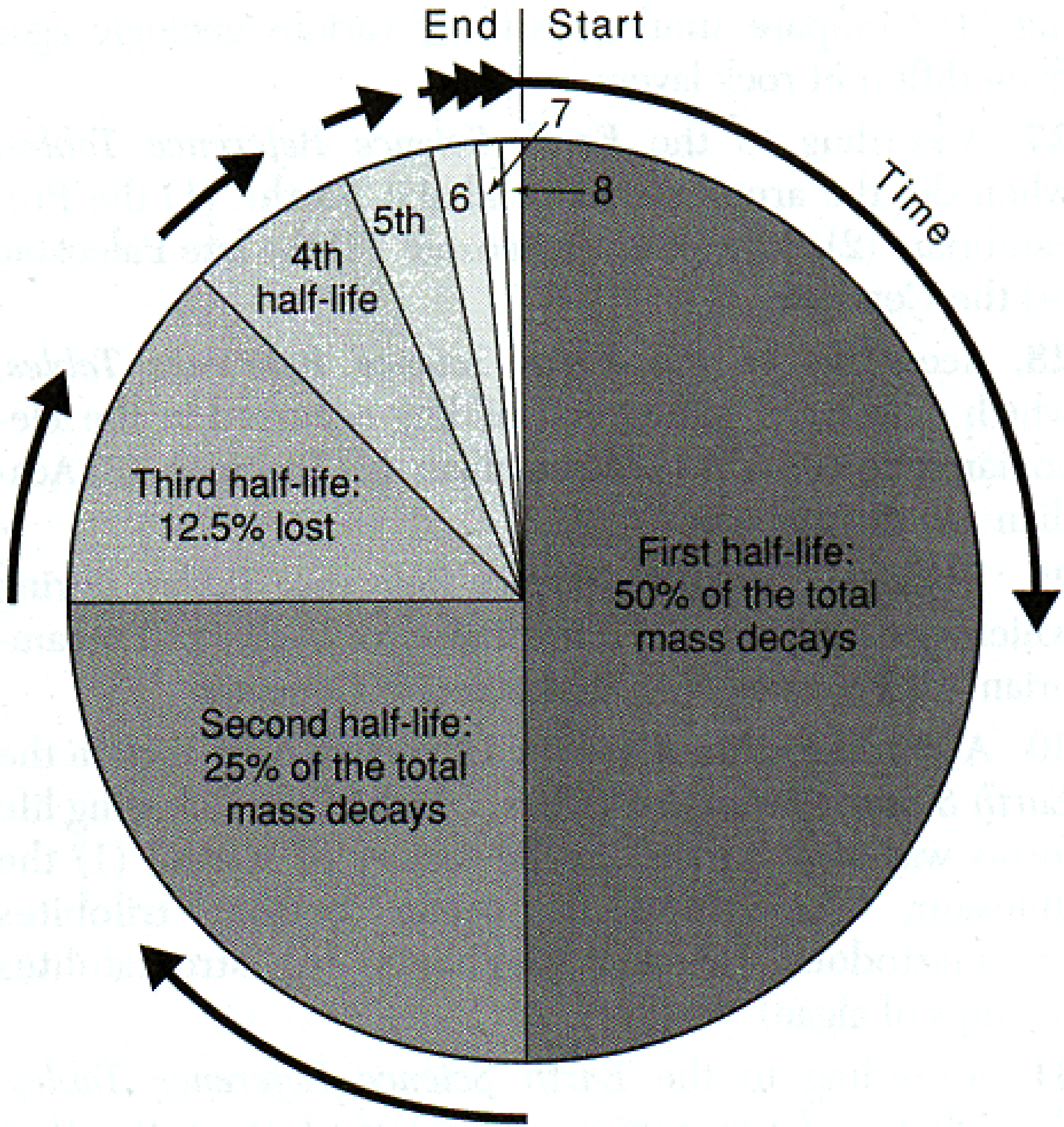


Isotope Stability - Half-life

- The stability of an isotope can be determined by looking at the half-life of the isotope. The half-life of a radioactive substance is the amount of time it takes for half of the original amount to decay. For example, if you start with 100 atoms of helium, half life is the time it takes for the sample to decay to the point that only 50 atoms of the original helium isotope remain. The shorter the half-life, the more unstable the isotope.

	Half-life	**Decay Mode**	**Decay Product**
Helium-6	0.802 s	β^-	Lithium-6
Chlorine-39	55.5 minutes	β^- and γ	Argon-39
Carbon-14	5730 years	β^-	Nitrogen-14
Uranium-238	4.51×10^9 years	α and γ	Thorium-234

- Another look



Example: calculating with half lives

- ^{14}C decays to ^{14}N with a half life of 5,730 years. If a fossil starts out with 52.4 moles of ^{14}C, how much ^{14}N will be present after 17,190 years?

- Step 1: How many half lives have passed?

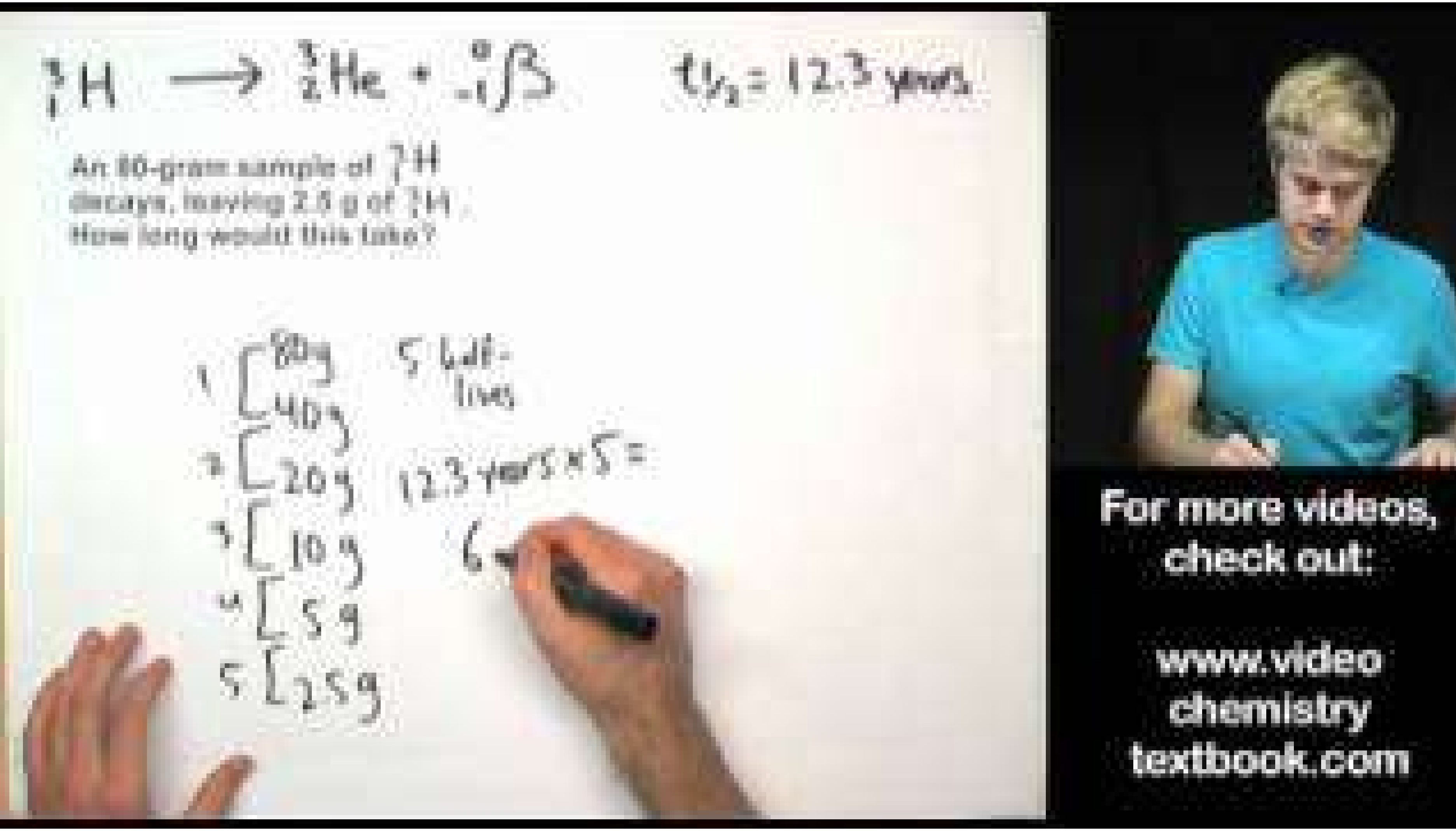
  $\frac{t_{total}}{t_{half-life}}$ = # of decay cycles $\frac{17{,}190\ years}{5{,}730\ years}$ = 3 cycles

- Step 2: Determine what percentage of parent & daughter exist

  1 half-life: 50-50, 2 half-lifes: 25-75, 3 half-lives: 12.5-87.5

- Step 3: Multiply the percentage by the original number of moles

  52.4 moles x 0.875 = 45.6 moles ^{14}N



An 80-gram sample of ${}^3_1H$ decays, leaving 2.5 g of ${}^3_1H$. How long would this take?
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