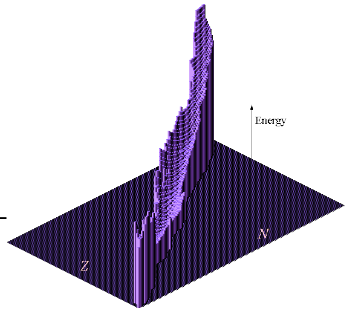
Exploring the Chart of the Nuclides



Introduction and background: We live in on a planet with plenty of big atoms – lots of silicon, iron, gold – all the way up to uranium. Each of these atoms has a nucleus composed of protons and neutrons, held together by a very short range "strong force" that overcomes the long range repulsive Coulomb force which pushes the protons apart, getting ever more forceful as the protons get close to each other until the strong force takes over. How did these nuclei form in the first place, if the parts have such tremendous repulsion?

Nuclear physicists have found that, given the heat and pressure at the cores of stars, nuclei of the smallest element, hydrogen (Z=1), can be fused together to form helium (Z=2), and at even higher pressures and temperatures, helium nuclei will be smashed together hard enough to fuse into bigger elements, forming elements up to iron (Z=26).

But nucleosynthesis stops at Z=26 – fusing bigger nuclei consumes energy rather than releases it, so it's like pushing rocks uphill; nature prefers to let them roll down. How, then, do bigger atoms get made? Where did the copper in your pocket (Z=29), the radon in your basement (Z=86), and the uranium in your bomb (Z=92) come from?

Each of these nuclei has a number of neutrons in addition to the protons that define each element. The number of neutrons can vary, creating different isotopes of each element. So, for example, having 6 protons makes a nucleus carbon, but the number of neutrons could be 6 or 7 or 8, yielding isotopes of carbon known as C-12, C-13, and C-14.In the following explorations, you'll determine which isotopes (or nuclides) are stable, how they could have formed, and how they transform into new nuclides following rules we've observed in nature.

Objectives:

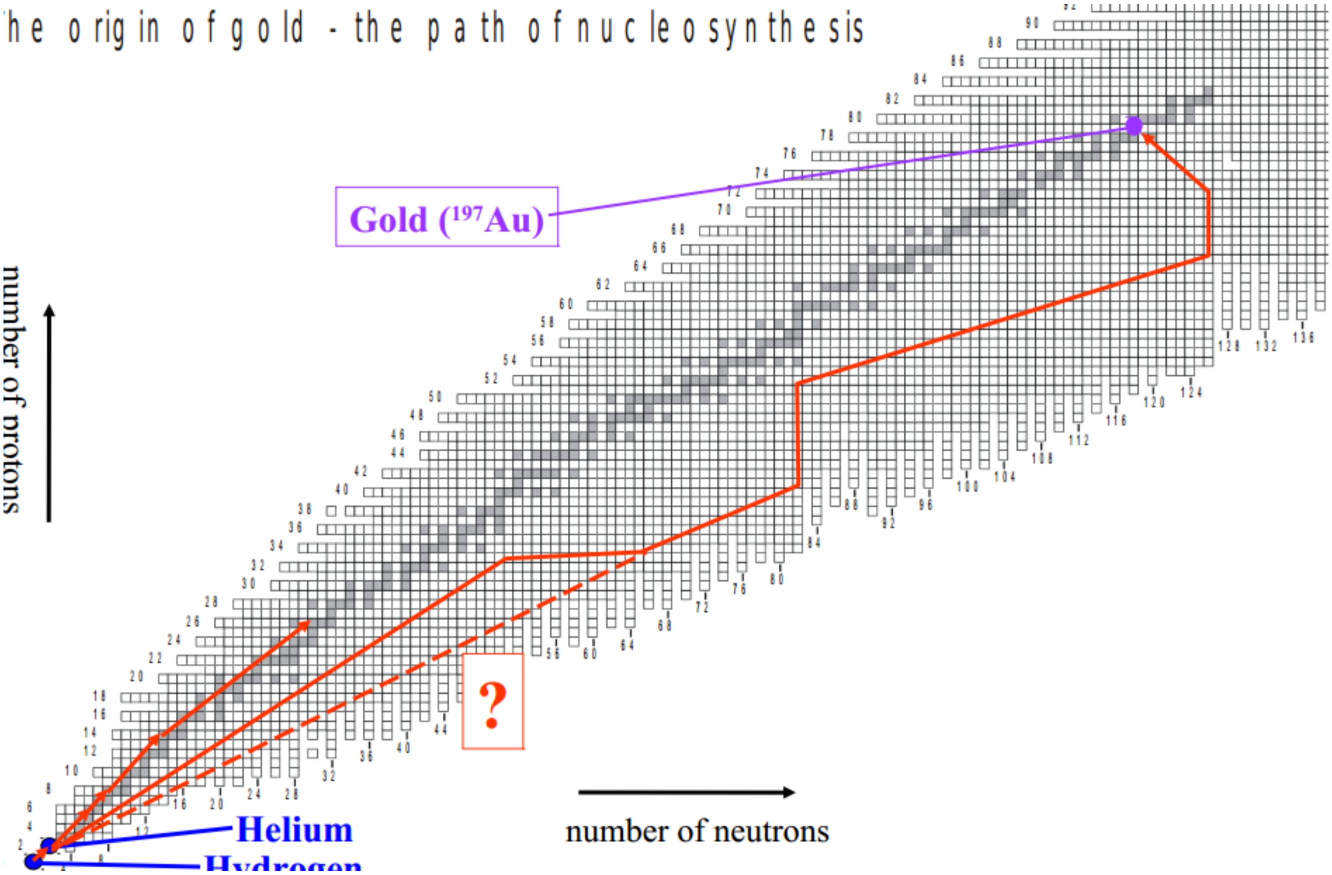
1. Students will be able to search the Periodic Table of the Elements to determine atomic masses and proton/neutron counts in a nucleus.
2. Students will be able to find nuclides of any mass on the Chart of the Nuclides, and determine nuclear decay transformations of two types, $^{-}$ and $^{+}$.

Explorations:

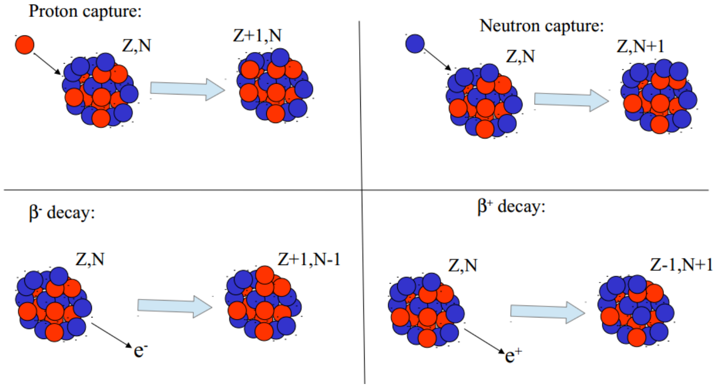
1. Using the Chart of the Nuclides on page 2, find which axis shows which nucleon (a term used for either a neutron or a proton) is present in any given nuclide. You will also need a periodic table. Find Zn-66 (note: zinc has 30 protons, so this nuclide will have 66-30=36 neutrons)

Find S-35   Find Ba-132   Find Hg-205

2. Not every combination of neutrons and protons is stable, just as not every stack of Legos is stable. Some fall apart spontaneously, as we'll study later. The dark gray boxes on the Chart represent stable nuclei. What are the stable isotopes of oxygen?
   What are the stable isotopes of boron? Of zinc? Of barium?



3. A nucleus might be energetically stable, so it will last for a really long time, just as a rock at the bottom of a hill will usually stay put. But a rock perched high on a ledge might fall down to a lower energy position at any time. A pencil balanced on its point will fall in short order. The nuclides shown in light gray boxes on the Chart have this energetically unfavorable condition, like the pencil, and will soon 'decay,' or move to a more stable, lower energy condition. Here's a picture of several possible decays:



For example, if a Mn-56 (unstable) undergoes $^-$ decay, an electron is ejected at high energy from the nucleus, and a neutron becomes a proton. So on the Chart, the nuclide moves from the Mn-56 box to the Fe-56 box, which is stable (Remember, it shed energy by ejecting the electron, and emitting light.). Note we went from 25 protons and 31 neutrons, to 26 protons and 30 neutrons. What do you get if Ag-112 undergoes $^-$ decay? Is it going to be stable?

Show what changed in this decay reaction:

Before: _____ protons ______ neutrons After: _____ protons _____ neutrons

Is Sr-84 likely to undergo $^-$ decay? Explain:

How many times must Cs-139 undergo - decay to reach stability? And what will it become?

4. Note that $^-$ decay requires a move up one and to the left one on the Chart. Study $^+$ decay to see how moves will be made on the chart. What do you find? Note that the particle taking away the energy this time is a positron.

   Will nuclides below the region of stability on the chart tend to undergo $^+$ decay, or $^-$ decay in order to reach stability?

   If Y-84 undergoes + decay, what will be the new nucleus formed?

   If Ir-193 is formed, what underwent $^+$ decay to form it?

Conclusion: This has been a partial introduction to the tools nuclear physicists, nuclear chemists, and astrophysicists use to understand how big atoms like we find on our planet have come to be from the hydrogen and helium that first formed in our universe after the Big Bang. As you can see, more processes can be used to get to every nuclide you see on the Chart, though many have not been studied in detail, or found in the stars, or made in accelerators here on Earth. Much work remains to be done!