Nuclear Chemistry Class Notes

Nuclear Chem refers to the nucleus, which is totally different than this whole class so far. We've been all about electrons since day one. There are 118 atoms now on the Periodic Table of the Elements. All have isotopes, that means chemically identical atoms with a different number of neutrons (some more, some less). Most of the time this just means they have a slightly different mass. No biggie at all. There are nearly 1500 different known isotopes, and all are stable, except for about 150 of them

Stable atoms have a nucleus that is "comfortable" with it's neutron to proton ratio. Let's look at three atoms, one small one, one medium sized, and one bigger one. Let's figure out the neutron to proton ratio for each.

size	name	Atomic Mass (most common isotope)	Atomic # (number of protons)	Number of Neutron	ratio of neutrons to protons
small	oxygen				
medium	copper				
larger	mercury				

Each of these atoms is stable, that means it's nucleus has a "comfortable" neutron to proton ratio. Smaller atoms have close to a 1:1 neutron to proton ratio. Medium sized atoms have a slightly higher ratio, closer to a 1.25:1 ratio. Larger atoms have a 1.5:1 ratio of neutrons to protons.

Sometimes the ratio of neutrons to protons reaches a point that is just gross for the nucleus, and quite literally, the nucleus needs to expel some of itself in an attempt to change the ratio of neutrons to protons. What gets expelled is called radiation, or radioactive particles. Sometimes (like having food poisoning) one big spit out is enough to bring about stability, sometimes it takes more than several steps to get back to stable.

Sometimes this is a quick process, sometimes it takes millions of years. All isotopes try to stabilize their nuclei in their own way, and at their own rate. They each spit out particular kinds of radioactive particles (or energy), and do so at a very, very regular rate, but each goes at it's own rate.

Table N lists 24 radioisotopes for us to review. Radioisotopes means radioactive isotopes (unstable). Let's look at table N now.

The first radioactive isotope is called Gold-198. It's symbol is ^{198}Au. On the periodic table we see the most common isotope of gold has mass of 197 amu. This radioactive one has one extra neutron, which is apparently enough to make it unstable. All gold isotopes have 79 protons, that's what makes them gold in the first place.

How many protons, neutrons and electrons do each of these isotopes of gold have?

isotope	mass	number of	number of	number of	another way to
^{198}Au					
^{197}Au					

The ring on my left hand is made of gold-197. I know that for 2 reasons, it's still on my finger, and I am not dead from radiation poisoning. Both reasons make me happy.

This Au-198 emits radiation. That's listed as the "decay mode" in table N. This gives off radiation with a cool lower case Greek letter called beta, with a negative sign. Draw it into the boxes below

In the chemical symbol, each part means…

BETA PARTICLES	Greek Letter Symbol	Chemical Symbol

When beta radiation (radioactive particles) are emitted by a nucleus of Au-198, the ratio of the neutrons to protons changes, which is the reason it seems to happen. The math works this way: the numbers "on the top" equal across the arrow. The numbers on the bottom equal across the arrow as well. Then we use the Periodic Table to see what happens! Strangely, when an atom emits radiation, it transmutes (changes into) a different kind of atom. It's easy to do the math, but why or how this is possible is still pretty hard to explain.

$$^{198}_{79}\text{Au} \longrightarrow {}^{0}_{-1}\text{e} + {}^{198}_{80}\text{Hg}$$

In this case, atoms of gold become atoms of mercury. This is not "normal" chemistry but it is nuclear chem. Atoms that are unstable will transmute into other atoms when the nucleus attempts to get more stable.

Look now at radioactive carbon, carbon-14. Most carbon has mass of 12 amu, this one has 2 extra neutrons and is unstable. It emits beta radiation, what will it transmute into?

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{0}_{-1}\mathrm{e} \; +$$

We can say this several ways: Carbon-14 emits beta radiation and transmutes into nitrogen-14. Carbon-14 undergoes beta decay and becomes nitrogen-14. C-14 emits radiation and changes into nitrogen-14.

Show the transmutations for these 2 isotopes (add in all numbers and symbols):

$$^{60}\mathrm{Co} \longrightarrow$$

$$^{3}\mathrm{H} \longrightarrow$$

The isotope ^{37}Ca does something different, it emits a different kind of radiation. ^{37}Ca emits a particle

named the __________________ particle. It has two different symbols as well, which are _________________

Show the transmutations for these 2 isotopes (add in all numbers and symbols):

$$^{37}\mathrm{Ca} \longrightarrow$$

$$^{53}\mathrm{Fe} \longrightarrow$$

Francium-220 undergoes a third type of transmutation by emitting particles called _____________________ particles. The chemical symbol for this is

Show the transmutations for these 2 isotopes (add in all numbers and symbols):

$$^{220}\mathrm{Fr} \longrightarrow$$

$$^{239}\mathrm{Pu} \longrightarrow$$

Show the transmutations for these 3 isotopes (add in all numbers and symbols):

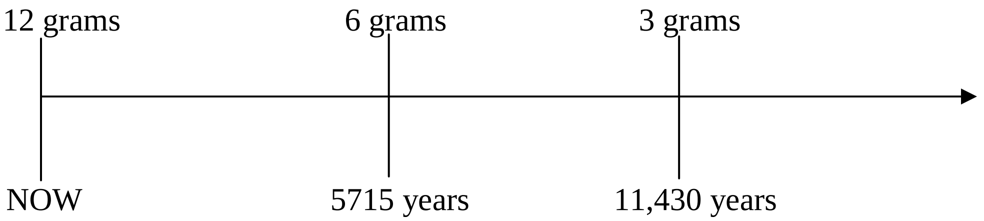
$^{19}\mathrm{Ne} \longrightarrow$

$^{222}\mathrm{Rn} \longrightarrow$

$^{90}\mathrm{Sr} \longrightarrow$

Radioactive Decay occurs as slow or as fast as it wants to. 100 grams of radioactive Au-198 will decay into 50 grams of Au-198 in 2.695 days. That amount of time is called its HALF LIFE. Why is it that long exactly? No one can explain that. That's a Nobel Prize waiting for you. The half life of C-14 is 5715 years. Why does it take THAT long? Who knows? That means if you had 100 grams of C-14, it would take 5715 years for half of it to transmute, leaving you with just 50 grams of C-14.

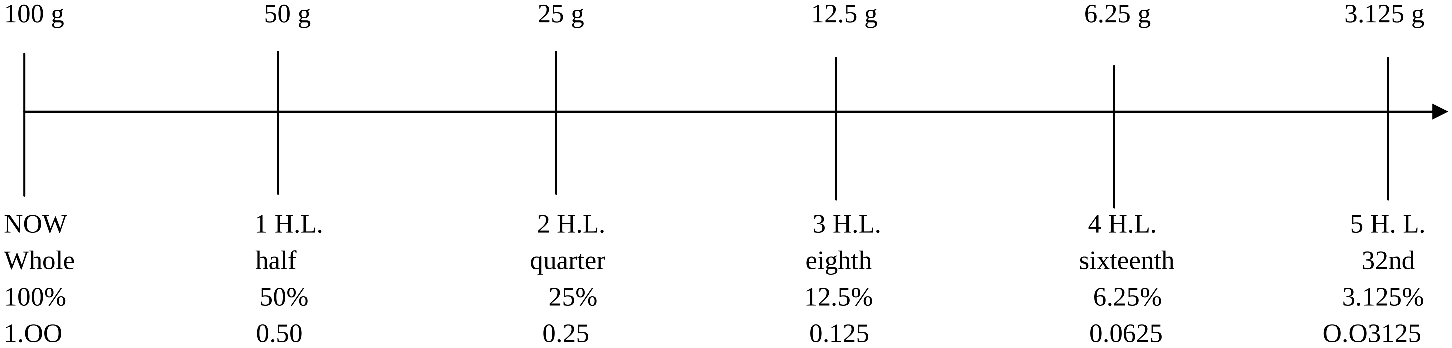
If you have 12 grams of radioactive C-14, how long would it take until you have just 3 grams of it? To figure this sort of half life problem out, you need a T-chart.



In our class we will always work this out to a "whole number" of half lives. In college, with a fancy formula, you could figure out how many years it would take to have just 2.75 grams left. It's not that hard, but we'll stick to the easy problems.

Half life problems can be done in TIME, in MASS, in HALF LIVES, FRACTION LEFT OVER, or DECIMAL LEFT OVER. Review this T-Chart for all.

You have 100 grams of Au-198. This is how it proceeds to decay



100 g	50 g	25 g	12.5 g	6.25 g	3.125 g
NOW	1 H.L.	2 H.L.	3 H.L.	4 H.L.	5 H. L.
Whole	half	quarter	eighth	sixteenth	32nd
100%	50%	25%	12.5%	6.25%	3.125%
1.OO	0.50	0.25	0.125	0.0625	O.O3125

If you have 128 grams of cesium-137, how long until you have just 8 grams left? Then, what percent of the whole will still be radioactive cesium?

How long is the half life of U-233? (write out in number) ____years

How long is the half life for iron-53? ____

Which has a longer half life, strontium-90, or cesium-137? _____________________________

There are six kinds of radiation listed in table O. Answer these questions….

What is the particle with the greatest mass? ________

What is the name of the radiation that has no mass and no charge? ______________

What is the chemical symbol for a positron? ____________________

What 3 Greek letters that describe the first 3 types of radiation? ____

Which of those is negatively charged? ___________________

Which of the six radiation types is blocked by paper or skin? ___________________

Which has the MOST penetrating power of them all? _________________

Which has mass but no charge? ________________

Which radioactive particle has mass and a +1 charge? _________________

Which radioactive particle has mass and a +2 charge? _________________

Which radioactive particle has NO mass and a +1 charge? _________________

Which radioactive particle has mass and NO charge? _________________

Which radiation type is good for living things? _______________________________

When radioisotopes undergo decay, it just happens NATURALLY. No human acts can make it happen, make it go faster, or slow it down. It's unaffected by heat, cold, pressure, etc. It just happens. How do these radioactive isotopes "know" when to transmute, and when it's the atom next to it's time to transmute instead? That's another Nobel Prize waiting for you.

Sometimes scientists can force a transmutation, make ARTIFICIAL TRANSMUTATION occur. To do such a thing scientists blast atoms with neutrons (or protons, alpha particles, etc.) and hope to hit the nuclei that they are aiming at. If one of these particles hits just right, and "gets into the nucleus", the nucleus can become so unstable that it will transmute artificially.

If scientists can do this enough in a short time, in a close space, it can set off what's called a chain reaction. This is a kind of nuclear explosion.

The "splitting" of an atom can be caused by bombarding uranium-235 nuclei with neutrons, they can create U-236, which is unusually unstable. This isotope splits into two other atoms, Kr-92 and Ba-141. It releases three more neutrons, which then will split more U-235 isotopes. This 1 neutron creates 3 neutrons, which creates 9 neutrons, which creates 27 neutrons, which creates 81 neutrons, which creates 243 neutrons, etc. Makes for an ever increasingly big reaction. With sufficient U-235, in seconds this can occur so many times that a nuclear explosion big enough to destroy a large city can happen. Below is a simplified version of this. We will discuss this at length soon.

$$^{235}\text{U} + \text{n}^{\text{o}} \rightarrow {}^{236}\text{U} \rightarrow {}^{92}\text{Kr} + {}^{141}\text{Ba} + 3\text{n}^{\text{o}} + \text{energy}$$

It's important to note the energy at the end of the equation. It's not a lot of energy when one uranium isotope is split into krypton and barium, but as this cycles, that amount of energy becomes mind bogglingly large.

Let's first look at the math. 235 + 1 = 236 = 92 + 141 + 3 = 236 total. It appears that all of the amu are accounted for. Now it's time for some truly out of the world ideas. Try to hold them close for a while….

In very advanced chemistry and physics there are four basic forces: gravity, the weak force, electromagnetic, and the strong force. They are listed in "strength" order. Gravity is the weakest, it holds large objects together. The weak force allows for some radioactive decay. Electromagnetic force is involved with chemical bonding, and finally, the strong force is what holds the protons and neutrons together so tightly in a nucleus. That's a very strong force, as the protons are all positively charged and should repel from each other. They don't because the force holding them together is literally, very strong.

Remember Albert Einstein? He gave us a cool formula once, you already know it. $E=mc^2$. Very simply, that means that energy is equal to matter X the speed of light squared. The speed of light is a constant, a very, very big constant, squared here. The important part here is that energy = matter. It's the same, just with different units.

When U-235 becomes U-236, then splits apart into Kr and Ba, a very small amount of mass is converted into energy. The loss of mass approximates 0.10% of the original uranium, but, it's multiplied by the huge constant (squared). This mass to energy transformation releases millions of more times energy than any kind of chemical reactions. Combustion is less than a mosquito to the elephant of fission (the splitting of uranium atoms).

The Law of Conservation of Matter appears to break, mass is lost, but Einstein was able to "find" this mass, which was converted into energy.

A second type of nuclear reaction is fusion. Fusion is when small atoms, usually hydrogen are squished into helium atoms. This also results in a very tiny conversion of mass to energy, but is incredibly more energetic than fission.

Fission reactions power a nuclear power plant and some nuclear bombs. The Sun is powered by fusion.

Simple fusion on the Sun, which has incredible pressure and temperature in it's core, is able to squish simple hydrogen atoms (4 at once) into helium atoms (emitting 2 neutrons in the process) and creating tremendous energy release.

On Earth, scientists cannot create that pressure or temperature, so a different version of fusion can be started. Using radioactive hydrogen isotopes, squished inside a chamber by the explosion of a fission bomb, can create a hydrogen bomb. The power released is uncontrollably huge, and these reactions have been used only in testing for weapons of mass destruction. The bombs dropped in Japan by the USA during the end of World War II were fission bombs, and relatively small by today's models. A hydrogen bomb is much, much more destructive. Below are the reactions that occur on the Sun, followed by fusion scientists can make happen.

Simplified Fusion on the Sun is done this way: $4H^{+1} \rightarrow {}^{4}He + 2n^{o}$ + energy

Simplified Fusion on Earth is done this way: ${}^{2}H + {}^{3}H \rightarrow {}^{4}He + n^{o}$ + energy

The radioactive isotopes of hydrogen used in Earth fusion are called deuterium and tritium (for mass of 2, and mass of 3). The "regular" isotope of the most common hydrogen atoms is called protium.

Nuclear fission is used by scientists all over the world to power nuclear power plants. All these plants do is create a lot of heat, boil a batch of water, the hot steam is pumped under high pressure through pipes and used to turn the blades of turbines. Turbines spin huge, powerful magnets around copper wire, which creates moving electrons, which is electricity.

Nuclear power has both positive points, and negative ones, which are the "pros" and the "cons".
How you feel about nuclear power is important, but your thoughts should be based in facts. Learn, think, then make the signs for your side of the protests. Here are some facts to ponder.

Some "Pros" in favor of nuclear power…

1. There are no green house gases produced with it, so global warming is lessened if we burn less coal or oil to make heat to produce electricity.
2. There is little waste in size, in fact ALL of the waste ever produced by all American nuclear power plants could easily fit onto our high school foot ball field, and only be 10-15 feet deep.
3. Nuclear power creates relatively cheap electricity once the plant is produced, and it employs many people.
4. No one has ever died from radiation poisoning, or from any reactor breakdown or leak.
5. Electricity is good, nuclear power makes heat easily and produces lots of electricity for cities, businesses, homes, and fun.

Some “Cons” against nuclear power...

1. The wastes produced are radioactive and dangerous for thousands (or millions) of years.
2. We don’t know where to put this stuff, nor can we bring it somewhere, or think that we can protect it from getting into the environment, or letting terrorists from obtaining it. Ask where it is right now.
3. Although the waste can’t explode like a nuclear bomb, it can be spread out by bundling it to regular explosives, creating “dirty bombs” that spread radiation, fear, and economic havoc.
4. Plants cost billions and are subsidized by governments at the expense of taxpayers.
5. No one wants to live near a power plant, in case they melt down.
6. They melt down, think of what happened a few years back at Fukashima, Japan, or to Chernobyl in Russia. At Three Mile Island in Pennsylvania there was almost a meltdown, but it was luckily averted at the last moments.
7. The longer we rely on nuclear we postpone the development of solar and wind power, both environmentally safer.

Nuclear chemistry in medicine.

Scientists and doctors have learned to use radiation and radioactive isotopes in medicine. Very small exposures to radiation, although bad for humans, can used to benefit us. For instance, some people with tumors or cancer are given radiation treatment. They are literally “shot” with beams of beta particles, which come from cobalt-60 atoms, to destroy the cancer. The beta radiation is aimed only at the tumors, which kills them. On the way into the body, the radiation also kills healthy cells. The thought is that killing the cancer is primary and needed, hopefully the cancer can be destroyed and then the rest of the body can recover. This does work.

Radioactive Iodine-131 is sometimes injected into a person’s veins (small amounts) to see if that person’s thyroid gland (in their neck) absorbs iodine properly. At a set time later, a special radiograph scan is taken of their neck which measures the uptake of this iodine. If insufficient radiation is detected, doctors know that the gland is not functioning properly and hormone therapy is needed. The amount of iodine is tiny and the half life is short, that the exposure is small enough to help more than harm.

Scientists can also use radioactive carbon to date how old once living material (frozen mammoths or saber tooth tigers, for example) are. Radioactive carbon-14 is a very small portion of all carbon and is formed when neutrons from the Sun blast into atmospheric nitrogen, forming C-14. Plants absorb carbon in the form of CO_2 during photosynthesis. Animals and people eat these plants, people eat animals as well. The amount of radioactive carbon is nearly constant, and is in all living things in the same proportion. Although very small, since it emits beta radiation, it’s easily detectable by scientists.

Once something dies, it stops absorbing C-14, but it keeps transmuting. Over time, the amount that transmutes is measurable. In 5715 years (the half life) only half the expected C-14 is present. If an animal dies, and is physically preserved in ice, or buried in any protective way, then found, the C-14 to C-12 ratio c an be measured, and with the math, it can be determined how long ago this dead organism stopped replacing C-14 (due to it’s death) by the ratio measured. It is accurate to 60,000 to 80,000 years, but not longer. Dinosaurs have been dead far too long to measure C-14 levels.