

## Chapter 24 - Nuclear Chemistry

We are now entering a new realm: whereas everything we've looked at till now has been founded on electrons' behavior (or the implications of such), we will now be dealing with nuclei.


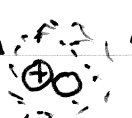

Electron  $\rightarrow$  chemical reactions, properties

- atoms don't change identity
- electrons are shared or transferred
- energy changes are relatively modest
- reaction rates depend on concentration, temperature, etc.

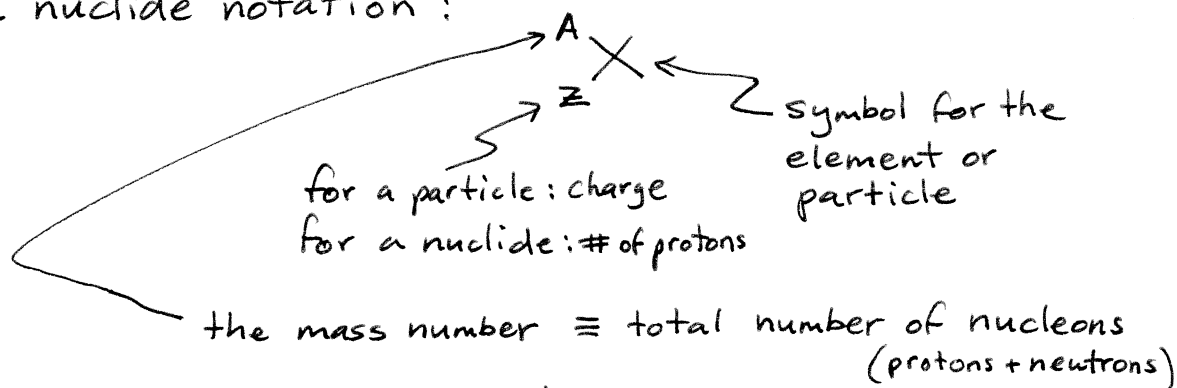
None of this applies to nuclear reactions in which nuclear particles are involved.

### \* Radioactivity, nuclear stability (24.1)

- A nucleus can be composed of any number of neutrons and protons that are approximately equal. (The atom adds in # electrons = # protons.)
- Some combinations are stable, some are less likely (but still stable  $\rightarrow$  last indefinitely), and some are unstable and must change the nuclear composition (radio active).

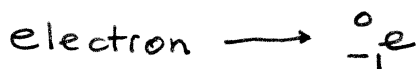
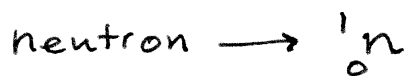
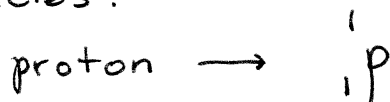
e.g. hydrogen (stable)  ; deuterium (less common)  ; tritium (unstable) 

These three different types of hydrogen are isotopes of hydrogen. Each of these can be tagged with the nuclide notation:

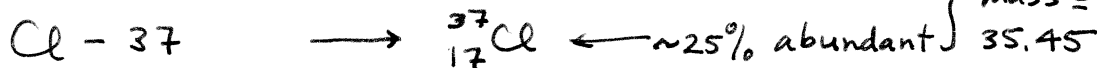
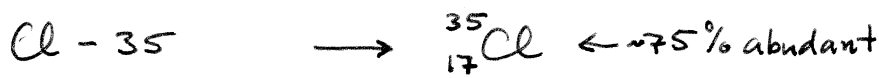
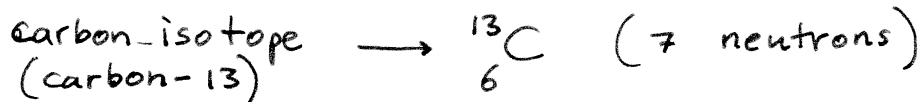
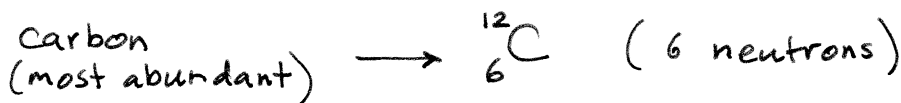
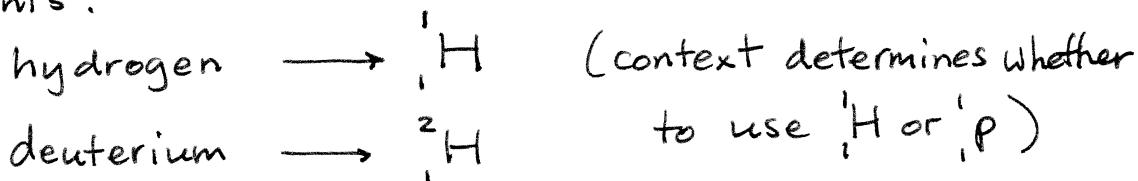


### Some examples

particles:



elements:

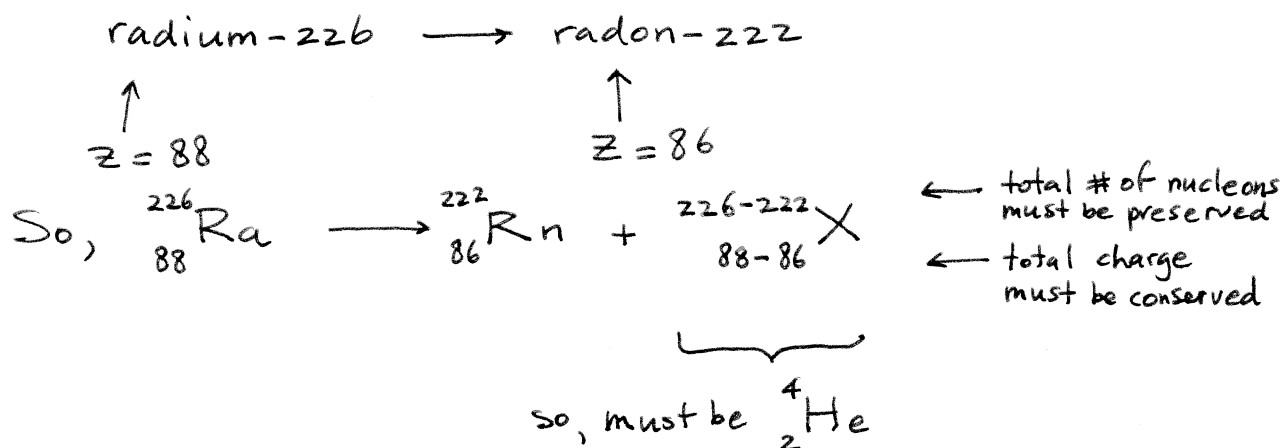


} atomic mass = 35.45

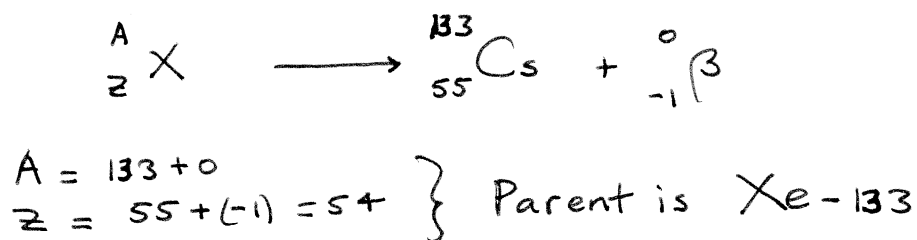
Radioactivity was discovered by Becquerel and first thoroughly investigated by Marie Curie. They and others found that the nuclide of a given chemical can decay to become the nuclide of another through these processes:

- emitting alpha particles ( $\alpha$ ) which consist of 2 protons and 2 neutrons, hence symbol  ${}^4_2\text{He}$ .
- emitting beta particles ( $\beta$ ) which have no mass but a minus one charge, i.e., equivalent to energetic electrons, so also given symbol  ${}^0_{-1}\beta$ .
- emitting gamma rays ( $\gamma$ ) which are just high-energy photons with no charge or mass, so also given the symbol  ${}^0_0\gamma$ .
- capturing an electron, which is then totally absorbed by the nucleus; symbol is  ${}^0_{-1}e$  (note similarity to  $\beta$  particle - however, here the particle originates with the atom's electron shell, not the nucleus)
- emitting positrons, the "antiparticle" (same mass, opposite charge) to the  $\beta$  particle; symbol thus is  ${}^0_{+1}\beta$ .

Nuclear reactions (parent  $\rightarrow$  daughter) are also written as equations:

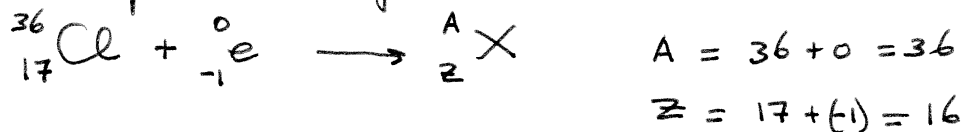


This was an example of alpha decay. Beta decay example: follow-up 24.1



or  ${}_{54}^{133}\text{Xe}$  with 54 protons and 79 neutrons

Electron capture example:



So daughter is sulfur-36:  ${}_{16}^{36}\text{S}$

Gamma rays are emitted in most nuclear reactions (releasing energy) but does not itself cause changing of nuclide.

Nuclear stability - not totally understood, but can be correlated with some parameters:

- Neutron/proton ratio ( $N/Z$ )  $\approx 1$  up to  $Z = 20$  (calcium). Only  ${}^1_1\text{H}$  and  ${}^3_2\text{He}$  have  $N/Z < 1$ .

- As  $Z$  increases,  $N/Z$  gradually increases

<u>isotope</u>	<u>N</u>	<u>Z</u>	<u>N/Z</u>
iron-56	30	26	1.15
silver-107	60	47	1.28
tungsten-184	110	74	1.49
bismuth-209	126	83	1.52

} Table 24.2 shows the "band of stability"

- Above  $Z = 83$ , no stable nuclides (i.e., 25 known elements are radioactive, only)

- Elements with even  $Z$  have more stable isotopes than those with odd  $Z$ ; even

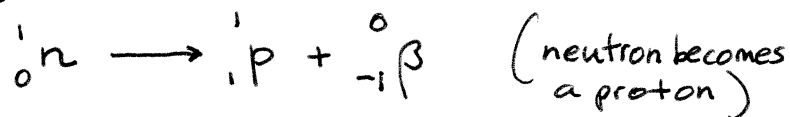
$N$  also helps:

<u>Z</u>	<u>N</u>	<u># of stable nuclides</u>
even	even	157
even	odd	53
odd	even	50
odd	odd	7
		<hr/>
		267

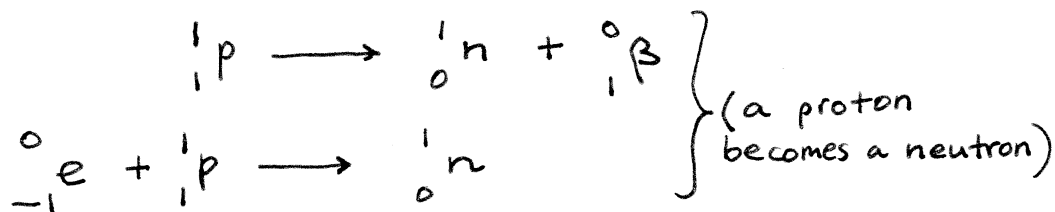
(analogous to electron pairing stability? and concept of electron shells?)

- There are "magic numbers" of either  $N$  or  $Z = 2, 8, 20, 28, 50, 82, N = 126$  (are exceptionally stable).

- Overall stability is determined by the balance of proton-proton repulsive forces versus nucleon-nucleon "strong force" that is attractive.
- Strong force only operates at nuclear distances (i.e., not outside of nucleus).
- Mode of decay depends on  $Z$  and  $N/Z$ :
  - (1) Since  $Z > 83$  elements are too heavy proton rich to be stable, no matter how many neutrons, they go towards stable nuclides by releasing  $\alpha$  protons at a time - via  $\alpha$  decay ( ${}^4_2\text{He}$ )
  - (2) Neutron-rich nuclides (above the band) high  $N/Z$ , and need to emit a  $\beta$  particle

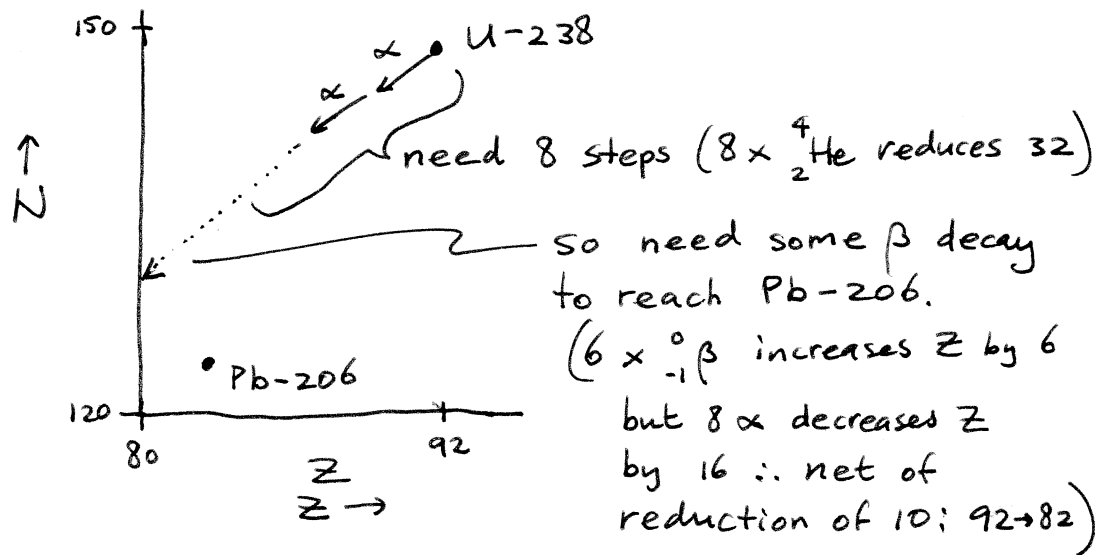
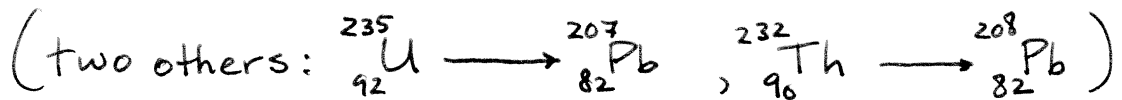
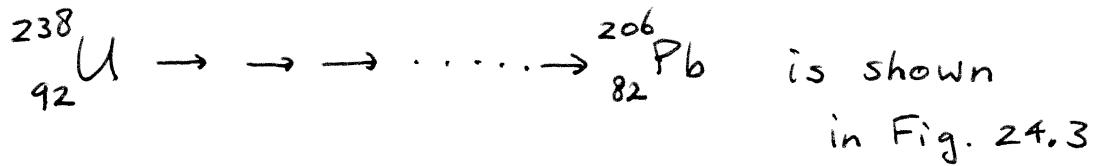


- (3) Neutron-poor nuclides (below the band) with low  $N/Z$  need to emit a positron or capture an electron



Follow-up 24.3: mode of decay for  ${}_{26}^{61}\text{Fe}$ ,  ${}_{95}^{241}\text{Am}$ ?  
 ${}_{26}^{61}\text{Fe}$  has  $N=35$ ,  $Z=26$ ,  $N/Z=1.35$ : too high  $\therefore \beta$  decay  
 ${}_{95}^{241}\text{Am}$  is too heavy  $95 > 83$ :  $\alpha$  decay

Decay series - steps taken by heavy elements ( $Z > 83$ ) to get down to the nearest, very stable nuclide: Pb-206. (remember that Pb has  $Z = 82$ , one of the "magic numbers")



Total # of steps : 8 @  $\alpha$  decay of  ${}^4_2\text{He}$   
 6 @  $\beta$  decay of  ${}^0_{-1}\beta$

