Department of Chemistry
University of Texas at Austin

Name:__________________

Nuclear Chemistry Unit Activity – Nuclear Energy KEY

Look at the following nuclear changes. For each group fill in the missing nuclides or particles by balancing the equation.

Group A

$^{2}_{1}H + ? \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$ Missing: $^{3}_{1}H$

$2\,^{3}_{2}He \rightarrow ? + 2\,^{1}_{1}p$ Missing: $^{4}_{2}He$

$2\,^{12}_{6}C \rightarrow {}^{23}_{12}Mg + ?$ Missing: $^{1}_{0}n$

$? + {}^{4}_{2}He \rightarrow {}^{12}_{6}C$ Missing: $^{8}_{4}Be$

Group B

$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{145}_{57}La + ? + 3\,^{1}_{0}n$ Missing: $^{88}_{35}Br$

$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{95}_{42}Mo + {}^{139}_{57}La + 2\,^{1}_{0}n + ?$ Missing: 7$^{0}_{-1}$ß

$^{240}_{94}Pu \rightarrow {}^{34}_{14}Si + ?$ Missing: $^{206}_{80}Hg$

$^{231}_{91}Pa \rightarrow {}^{207}_{81}Tl + ?$ Missing: $^{24}_{10}Ne$

1. What do the reaction in Group A have in common?

Lighter nuclei are coming together to create heavier nuclei (fusion).
coming together... fuse together... fusion!

2. What do the reaction in Group B have in common?

Heavier nuclei are breaking apart into lighter nuclei (fission).

All of these reactions are exothermic. This is because the potential energy of nuclei (particles) in the products is lower than that of those of the reactants. This energy change can be quantified by measuring the reaction. Alternatively we can predict this difference if we know the masses of the products and reactants.

3. Use the masses given below to calculate the energy change in the first reaction in group A.

$^{2}_{1}H$ 2.01355 amu $^{3}_{1}H$ 3.01605 amu
$^{4}_{2}He$ 4.00151 amu $^{1}_{0}n$ 1.00866 amu
1 amu = 1.6605×10^{-27} kg
c = 2.998×10^{8} m s^{-1}

$$\Delta E = \Delta mc^2$$

$$\Delta m = m_{products} - m_{reactants}$$

$$\Delta m = [{}^{1}_{0}n + {}^{4}_{2}He] - [{}^{2}_{1}H + {}^{3}_{1}H]$$

$$= [1.00866 + 4.00151] - [2.01355 + 3.01605]$$

$$= [5.01017] - [5.0296]$$

$$= -0.01943 \text{ amu}$$

we need to convert amu to kg because we want to have energy in units of joules which ($kg*m^2/s^2 = 1$ J).

$$\Delta E = (-0.01943 \text{ amu})(1.6605 \times 10^{-27} \text{ kg/amu})(2.998 \times 10^{8} \text{ m s}^{-1})^{2}$$

$$\Delta E = (-3.23\times10^{-29}\text{kg})(2.998 \times 10^{8} \text{ m s}^{-1})^{2}$$

$$\Delta E = -2.899 \times 10^{-12} \text{ J per reaction}$$

This change in energy is negative, which indicates an exothermic reaction.

$$2.899 \times 10^{-12} \times 6.022 \times 10^{23} = -1.75 \times 10^{12} \text{ J/mole}$$

4. A different way to look at the energy difference is from the binding energies. This the energy of the nuclide (the bare nucleus of the element) to the energy of separated nucleon (the protons and neutrons). Since the reaction is exothermic the binding energies of the products must be lower than the binding energies of the reactants. That is the combination of protons in neutrons in a He-4 nucleus is lower in energy than the combination in a H-2 + H-3.

Short Lecture on binding energies of different stable isotopes.

5. We have now looked at the trend in binding energies of stable isotopes. What about the trends in stability of different isotopes of the same element? Why are some elements stable and other are not? This is a question of high energy physics and the nuclear strong force. However, here we can explore the trends so that we can understand the different types of radioactive decay.

The chart on the next page shows the stable isotopes of all of the elements. They are depicted on a graph of the number of neutrons vs the number of protons.

How would you describe the stable isotopes from this graph?
At first it seems like stable isotopes occur when there are the same number of protons and neutrons (a 1:1 ratio). However, as the size of the nucleus grows, it seems as though having more neutrons than protons is stabilizing. Also, there are no stable isotopes that have more protons than there are neutrons.

Is the 1:1 proton to neutron ratio the most stable?
Stable for light elements, up to about atomic number 15
after that, need more neutrons, to about a 1:1.5 proton to neutron ratio

Is there an exact formula to predict the stability of a given isotope?
No (no simple formula)

What evidence is there that is more than one stable isotope for some elements.
Yes - there are vertical lines for some
So for one atomic number, there are multiple isotopes

Is there a trend?
There appears to be a general trend, yes. There is a band.

6. Some combinations of protons and neutrons are inherently unstable compared to others. These combinations will spontaneously change into more stable isotopes by the small particle. Below are three such examples of nuclear decay.

$${}^{215}_{80}Rn \rightarrow {}^{211}_{78}Po + {}^{4}_{2}He$$

(alpha decay)

${}^{82}_{40}Zr \rightarrow {}^{0}_{1}\beta + {}^{82}_{39}Y$ (positron emission)

${}^{74}_{30}Zn \rightarrow {}^{0}_{-1}\beta + {}^{74}_{31}Ga$ (beta decay)

Check understanding with clicker question

Also shown is a zoom in two different regions of the graph. Rn-215, Zr-82, and Zn-74 are unstable isotopes that have been added to the plot.

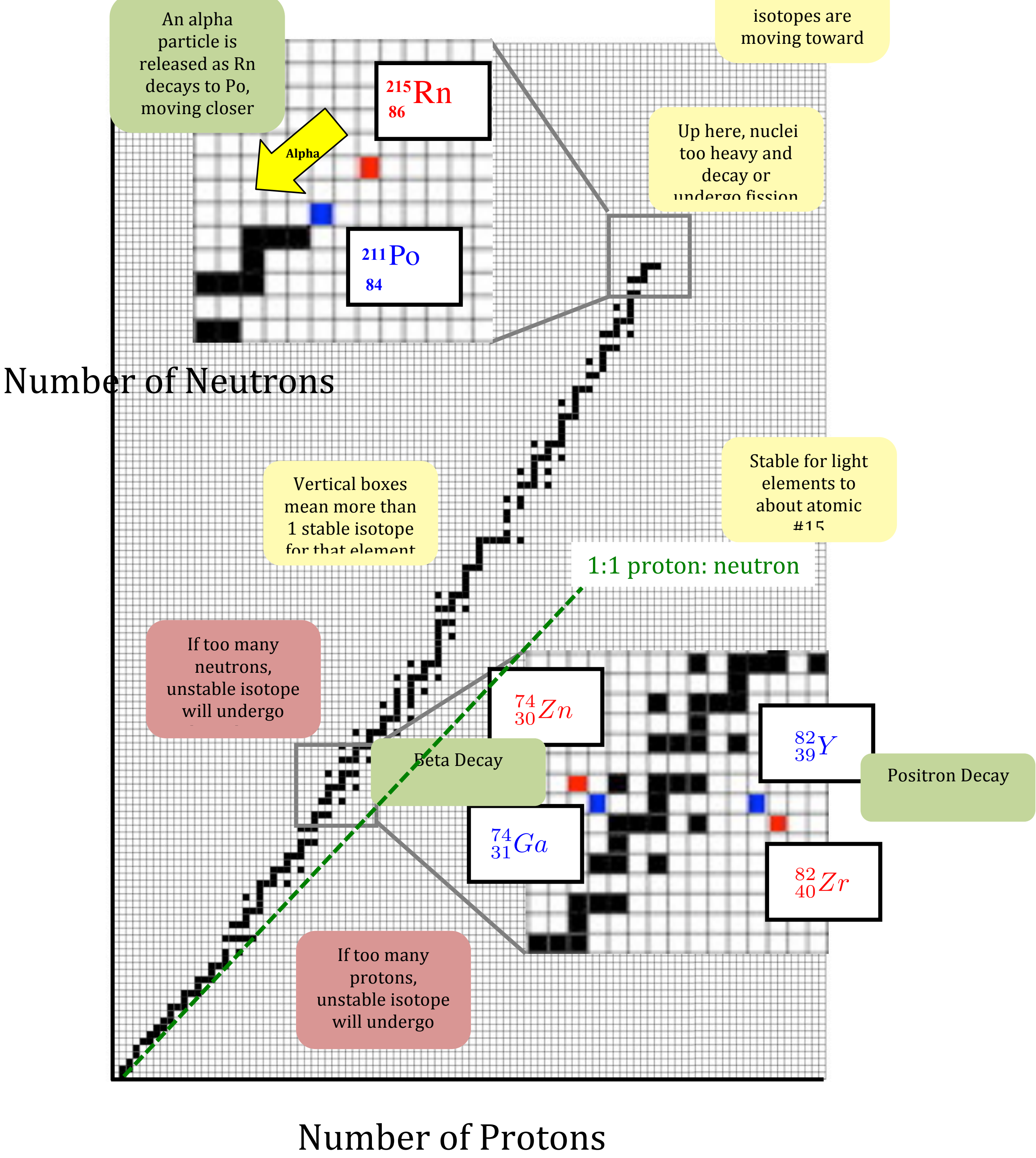
What can you say about the "stability" of the isotopes formed from these decays?
The products are closer to the trend line, so the products are more stable.

What type of decays would you expect for different regions of the graph?

- Positron Emission would happen below the trend line (to lower the charge number, but retain the number of neutrons).
- Beta Decay would happen above the trend line (to raise the charge number, but retain the number of neutrons).
- Alpha Decay would happen near the heavy nuclei where it would be possible to lose large amounts of charge and neutrons.

Name:________________

Stable Isotopes



Spontaneous decay occurs such that the isotopes are moving toward

An alpha particle is released as Rn decays to Po, moving closer

Up here, nuclei too heavy and decay or undergo fission

Vertical boxes mean more than 1 stable isotope for that element

Stable for light elements to about atomic #15

If too many neutrons, unstable isotope will undergo

If too many protons, unstable isotope will undergo

Revised CR 1/4/13