

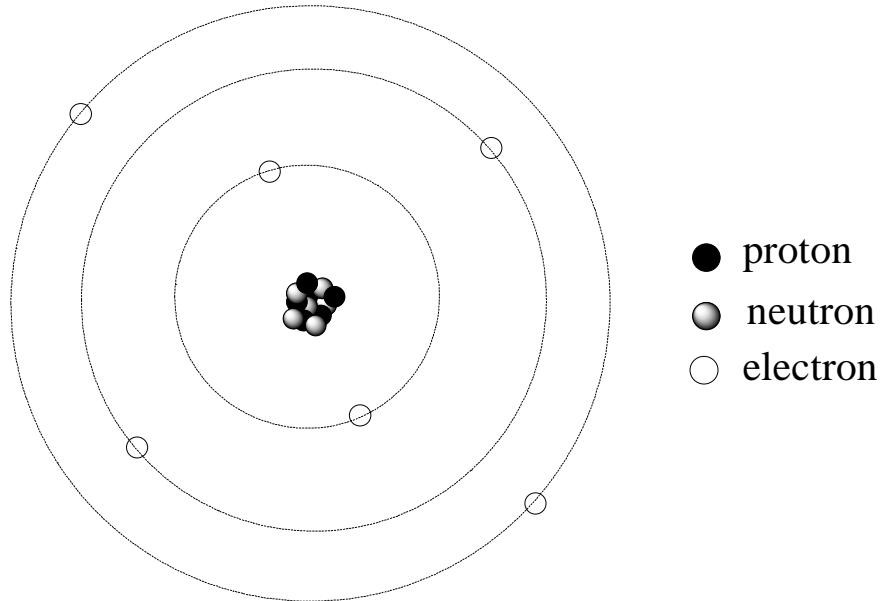
VI. Stability Problem Answers

Nuclear Stability

Bohr model of ^{12}C

0. Draw a Bohr Model of a ^{12}C (pronounced “carbon 12”) atom.

Note: Nucleus is shown as taking up much more space than it actually does.



1. What aspect of atomic structure seems inconsistent with your knowledge of basic physics?

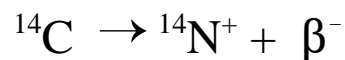
There is a very high concentration of positive charge in the compact nucleus. The repulsive electrostatic forces associated with the close proximity of the protons in the nucleus are being overcome by very strong binding forces associated with the formation of the ^{12}C nucleus. A discussion of these binding forces is beyond the scope of CHM 109. A physics course covers this.

2. Identify three aspects of nuclear structure that result in more stable nuclei. Which of these three items is quantitatively most important in making predictions about the stability of a broad range of nuclei?

- The n/p^+ ratio is a major determinant. For relatively small nuclei ($p^+ \# \leq 20$) a 1/1 ratio results in a stable nucleus. The ratio increases as nuclear size increases up to ~ 1.5 (for ^{209}Bi).
- At the large end of the scale, overall size is a factor. There are no indefinitely stable nuclei larger than ^{209}Bi .
- Even numbers of nucleons (n & p^+) tend to yield more stable nuclei than do odd numbers.

3. What eventually happens to unstable nuclei?

They decay radioactively into more stable nuclei. An example described in lecture was the conversion of ^{14}C into ^{14}N :

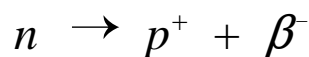


4. a) Fill in the table below for the subatomic particle composition of the indicated nuclides.

	^{18}F	^{19}F	^{20}F	^{20}F radioactively decays to:
				$^{20}\text{Ne}^+$
p^+	<u>9</u>	<u>9</u>	<u>9</u>	<u>10</u>
n	<u>9</u>	<u>10</u>	<u>11</u>	<u>10</u>
e^-	<u>9</u>	<u>9</u>	<u>9</u>	<u>9</u>

b) The ^{20}F nucleus is unstable and decays radioactively (by β^- [called “beta”] particle emission) to form $^{20}\text{Ne}^+$. A β^- particle has the same charge and mass as an electron. Write a chemical equation below showing how the nucleons of the ^{20}F nucleus changed during the reaction.

^{20}F has 9 p^+ and 11 n , while ^{20}Ne has 10 of each. In other words, ^{20}Ne has one more p^+ and one less n . One possible way to view this is that one of the neutrons in the ^{20}F nucleus changed and became a proton:

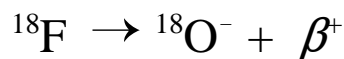


c) (*Challenging problem*) The ^{18}F nucleus is also unstable. When it decays, it emits an unusual subatomic particle called a positron β^+ . This particle has the same mass as the beta particle, but the opposite charge. Use the Law of Conservation of Charge to determine the nucleon changes that occur during positron emission, and what the product of positron decay by ^{18}F would be.

For charge to be conserved, a proton must be converted into a neutron in this decay mode:

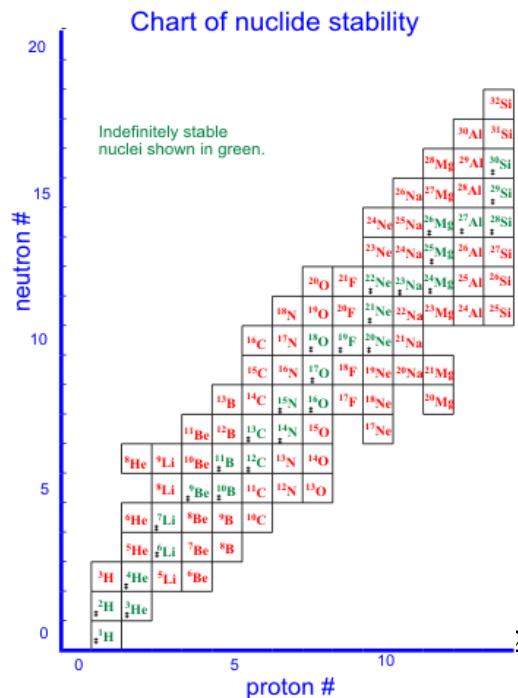


This would result in a nucleus with less proton than ^{18}F (therefore 8 protons) and one more neutron (therefore 10 neutrons). This nuclide is ^{18}O :



5. What is the Chart of Nuclide Stability?

This chart is a plot of the n/p^+ ratio of nuclei that also includes information about the stability of the nuclei on the plot. Usually neutrons are plotted on the vertical axis and protons on the horizontal.



6. Order the nuclides in part a) from least stable to most stable (first to last), indicating why you chose the order you did. Then do a separate ranking for the nuclides in part b).

a)	^{40}Ca	^{37}Ca	^{41}Ca	
	^{37}Ca ($t_{1/2} = 0.173$ sec)	^{41}Ca ($t_{1/2} = 8 \times 10^4$ yr)	^{40}Ca (stable)	
n/p^+ ratio	0.85	1.05	1.00	

Explanation: Ca is a relatively light nucleus, so it should be most stable with n/p^+ ratio = 1. Generally speaking the farther from 1 the ratio is, the more unstable the nucleus should be. This trend is observed. (Note that half-life is proportional to stability. A short half-life [e.g. 0.173 sec] indicates a relatively unstable nucleus.)

b)	^{242}Pu	^{243}Pu	^{29}S	^{32}S
	^{29}S ($t_{1/2} = 0.19$ sec)	^{243}Pu ($t_{1/2} = 4.98$ hr)	^{242}Pu ($t_{1/2} = 3.79 \times 10^4$ yr)	^{32}S (stable)
n/p^+ ratio	0.8125	1.585	1.574	1.00
odd v. even				
n	odd	odd	even	even
p^+	even	even	even	even

Explanation: While I would have expected you to predict that ^{29}S was less stable than ^{32}S and that ^{243}Pu was less stable than ^{242}Pu , I would not have expected you to make accurate predictions about the stability of the Pu isotopes relative to ^{29}S . You should have known that Pu isotopes would be less stable than ^{32}S (Pu is larger than Bi, the largest stable nucleus).

You could have used the even vs. odd criterion to predict that ^{243}Pu was less stable than ^{242}Pu . Likewise, the n/p^+ ratio criterion would predict that ^{29}S would be much less stable than ^{32}S .

Electronic Stability

0. a) In what groups (the vertical columns in the Periodic Table) are the representative elements found? (See Orbital Filling Periodic Table in Supplemental Information section if unsure.)

The representative elements are in groups IA & IIA and IIIA-VIIIA.

b) State the name of the guiding principle that determines electronic stability (of the representative elements).

The Lewis Octet Principle.

1. a) Write the electronic configuration of Ca. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

b) How many valence e^- does Ca have? 2. There are shown in blue above.

c) Is Ca the most stable form of calcium (under normal conditions)? Explain briefly.

No. Ca does not have a full valence shell (the $4s4p$ level).

d) What form of calcium would be more stable than Ca? Ca^{2+} is much more stable under most conditions. Its outermost shell is at the 3 level, and in Ca^{2+} the 3 level is full.

- e) Write an equation for a chemical reaction showing how Ca could be converted into a more stable form.



2. Will we have sufficient time in the class to decide whether Fe^{2+} is more than Fe or Fe^{3+} ? (Note: This will also apply to the other transition metals.) No, particularly because the relative stability of these is highly dependent upon the environment in which they are found.

3. Use the symbol (from the Periodic Table) shown at right to answer the following:

- a) What is the name of the element shown? Nitrogen
 b) How many protons are present in an atom of this element? 7
 c) In what group is the element found? Group VA
 d) How many valence electrons does an atom of this element contain? 5
 e) How much does the average atom of this element weigh? 14.0067 amu

7
N
14.0067

(atomic mass units)

f) Why did question e) above, use the phrase “average atom?” Many elements have more than one stable isotope. For example, 99.63% of the nitrogen on our planet is ^{14}N (weight = 14.00307 amu), while 0.37% is ^{15}N (weight = 15.00011 amu). The atomic weight given under the symbol for nitrogen on the Periodic Table is weighted average value for the weights of the different isotopes.

- g) Go to Wikipedia on the www. Enter Table of Nuclides in the search engine. Click on ^{15}N . What is the % natural abundance of ^{15}N . As of 10/15/08, 0.37%.

h) Does the answer to g) make sense if the weight of one atom of ^{14}N is 14.00307 amu. Yes! Explain. The atomic weight for N is given as 14.0067. This is slightly more than the weight of a ^{14}N atom. This makes sense, because a small fraction of the nitrogen on our planet is ^{15}N , which has a significantly heavier weight than ^{14}N . Therefore, the weighted average (takes into account the relative abundances of the different isotopes) weight should be more than 14.00307 amu.

- i) Given the following masses per subatomic particles:

$$\begin{aligned} p^+ &= 1.0073 \text{ amu} \\ n &= 1.0087 \text{ amu} \\ e^- &= 0.0054858 \text{ amu} \end{aligned}$$

What is the sum of the weights of the particles in a ^{14}N atom?

$$\begin{aligned} 7 p^+ \times 1.0073 \text{ amu}/p^+ &= 7.0511 \text{ amu} \\ 7 n \times 1.0087 \text{ amu}/n &= 7.0609 \\ 7 e^- \times 0.0054858 \text{ amu}/e^- &= \underline{0.0384006} \\ &14.1504006 \text{ amu} \end{aligned}$$

- j) Compare your answer in i) to the actual weight of an ^{14}N atom listed in h). What principle does this difference illustrate? The sum of the weights of the individual particles is less than the actual weight of an ^{14}N atom. This phenomenon is known as “the mass deficit.” The binding energy involved in holding the nucleons together in the nucleus is so large that a clearly measurable loss in mass is observed. Remember $e = mc^2$. i.e., Mass is just another form of energy.

4. a) Who (briefly) was Dmitri Mendeleev? A Russian chemist who did most of his work during the second half of the nineteenth century (1850-1900). He is credited with much of the creative thought associated with the development and adaptation of the Periodic Table.

b) Did the Periodic Table look the same in Mendeleev's time as it does now? If not, how is it different? It looks considerably different now because of the discovery/production of new elements.

c) Why (briefly) do scientists think Mendeleev's work was a significant scientific contribution?

Because Mendeleev was able to use his table to make accurate predictions about the existence and properties of elements before they were discovered.