Answer Key for Nuclear Chemistry Worksheet #1: Nuclear Decay Processes

Chem 160 – K. Marr

Key Questions

1. What does the symbol "$^{0}_{-1}e$" tell the reader? (*i.e.*, What does the superscript 0 mean? What can a subscript -1 possibly mean? Why is the beta particle symbolized with an e?)

   The superscript (mass number) 0 means that the particle has virtually no mass. The subscript (atomic number) means that the particle has "negative one protons". Since the proton has a +1 charge, this signifies that the particle has a -1 charge. The beta particle is symbolized with an "e" because the beta particle is an electron – which has a -1 charge and a mass equal to ~$^{1}/_{2000}$ that of a proton.

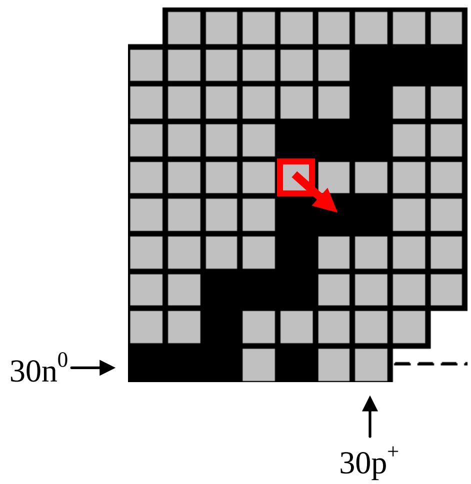
2. Nuclear equations (*e.g.*, $^{27}_{12}Mg \rightarrow {}^{27}_{13}Al + {}^{0}_{-1}e$) show "parent" and "daughter" nuclei. What is the mathematical relationship between the superscripts on the left-hand side and the superscripts on the right-hand side of the nuclear equation? What is the mathematical relationship between the subscripts on the left-hand side and the subscripts on the right-hand side of the nuclear equation?

   The sum of the superscripts on the left-hand side of the equation is equal to the sum of superscripts on the right-hand side of the equation. The sum of the subscripts on the left-hand side of the equation is equal to the sum of subscripts on the right-hand side of the equation.

3. Underneath each of the example nuclear equations of beta decay, there is a "blow up" of the plot of number of neutrons versus number of protons, showing the pertinent area. Why is there an added white arrow that points down one and to the right one in each plot?

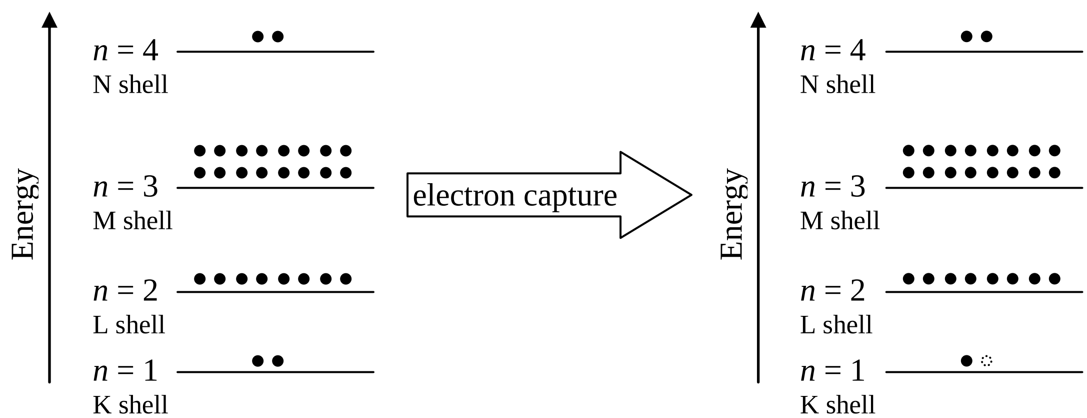
   The parent nucleus is, in essence, losing a neutron. Thus the arrow points down one since the number of neutrons is decreasing by 1. That neutron is becoming a proton, so the arrow points to the right one.

4. Nickel-63 is radioactive. Use the blown-up pertinent portion of the plot of the number of neutrons versus the number of protons to explain why we know that nickel-63 undergoes beta decay. (How many protons are in a nickel nucleus? How many neutrons are in a nucleus of Ni-63?)



Nickel has 28 protons in the nucleus, so Ni-63 has 35 neutrons. According to the plot, a nucleus with 28 p^+ and 35 n^0 is radioactive. But if the nucleus could decay by converting a neutron into a proton (*i.e.*, going one down and one to the right) , this would place the daughter on the band of stability.

5. A "by-product" of K capture is that a photon (very often either an X-ray or a γ-ray) is released by the daughter species. After the core electron is captured by the nucleus, a "hole" is created in the core shell.



Explain why a photon is emitted after an electron capture.

After the core electron is captured and a hole is created, the electron configuration will not be the lowest-energy one for the atom. An electron from a higher-energy shell (*e.g.*, the *n* = 4 shell) will drop down to fill the vacancy in the *n* = 1 shell. When this happens, the potential energy of the high-energy electron is converted into electromagnetic radiation, which corresponds to an X-ray or γ-ray photon.

6a. When an atom’s core electron is captured by the nucleus, what happens to the atomic number?

The atomic number decreases by 1.

b. When an atom’s core electron is captured by the nucleus, what happens to the species’ mass?

The mass number remains the same.

c. On a plot of the number of neutrons versus the number of protons, a beta decay was represented as an arrow pointing one step down and one step to the right. If an electron capture is to be represented as an arrow in the plot, where would it be pointing?

The arrow would point to the left one and up one.

7a. When a radioactive nucleus undergoes positron emission, what happens to the atomic number?

The atomic number decreases by 1.

b. When a radioactive nucleus undergoes positron emission, what happens to the species’ mass?

The mass number remains the same.

c. On a plot of the number of neutrons versus the number of protons, if a positron emission is to be represented as an arrow, where would it be pointing?

The arrow would point to the left one and up one.

8. What is the relationship between a positron and the electron? (Compare the superscripts and the subscripts of the symbols that represent these two particles.)

The electron and the positron have the same mass, but they have opposite charges. The positron is the anti-electron.

9. Compare and contrast the decay processes of electron capture and positron emission. What do they have in common? How are they different?

Both electron capture and positron emission involve a proton being converted into a neutron. But in electron capture a proton in the nucleus is combining with a core electron to become a neutron, and in positron emission a proton in the nucleus is giving up a positron (a positively-charged electron) to become a neutron – so electron capture involved the consumption of matter, but positron emission involves the production of anti-matter.

10. We used the symbol ${}^{0}_{-1}e$ to represent a beta particle. What is the symbol that represents an alpha particle? (What is the mass number of an alpha particle? How many protons does an alpha particle have? What element has this number of protons?)

The plot shows that the alpha particle is composed of 2 protons and 2 neutrons. The element with 2 protons is helium (He), and the mass number is 4. So the symbol for an alpha particle is ${}^{4}_{2}\mathbf{He}$.

Exercises

A. Write nuclear equations for each of the following radioactive decay processes.

① positron emission of Cs-127

$${}^{127}_{55}Cs \rightarrow {}^{127}_{54}Xe + {}^{0}_{+1}e$$

② alpha decay of ${}^{211}_{83}Bi$

$${}^{211}_{83}Bi \rightarrow {}^{207}_{81}Tl + {}^{4}_{2}He$$

③ electron capture of the nucleus having 49 protons and 60 neutrons

$${}^{109}_{49}In + {}^{0}_{-1}e \rightarrow {}^{109}_{48}Cd$$

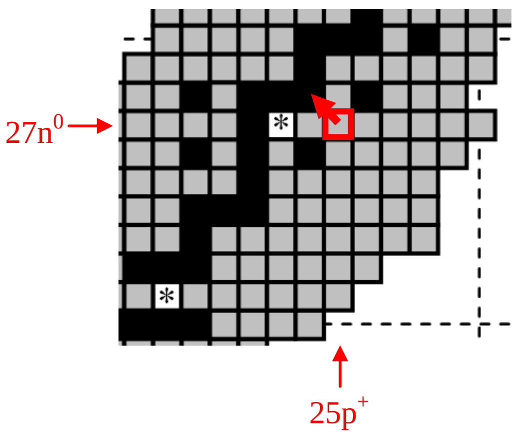
④ beta decay of zirconium-97

$${}^{97}_{40}Zr \rightarrow {}^{97}_{41}Nb + {}^{0}_{-1}e$$

B. Use the provided plot of the number of neutrons versus the number of protons to predict how each of the following nuclei are most likely to decay. (You may circle your answers.)

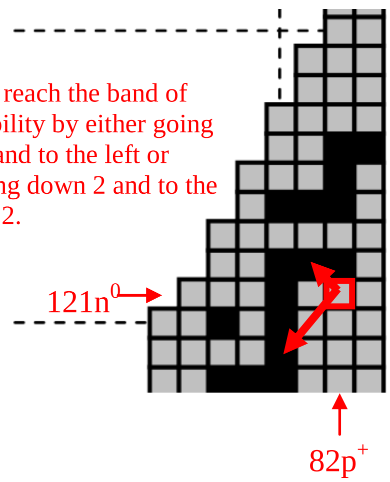
①	manganese-52	β decay	electron capture	positron emission	α decay
②	$^{203}_{82}Pb$	β decay	electron capture	positron emission	α decay
③	Be-8	β decay	electron capture	positron emission	α decay
④	antimony-126	β decay	electron capture	positron emission	α decay

①



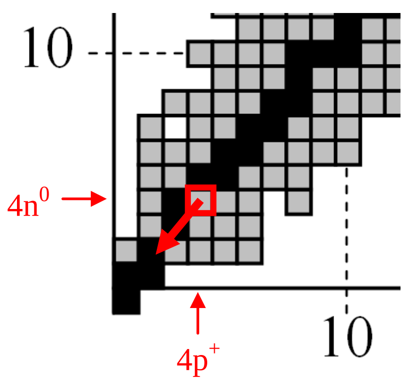
We reach the band of stability by going up and to the left,

②



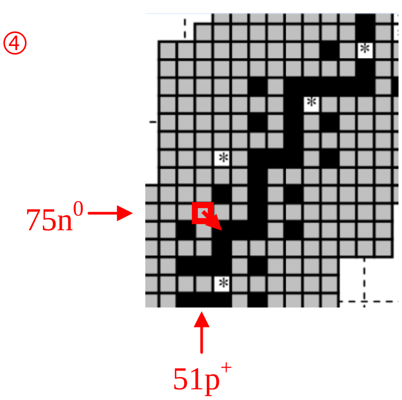
We reach the band of stability by either going up and to the left or going down 2 and to the left 2.

③



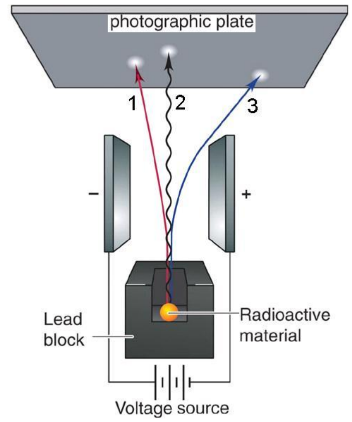
We reach the band of stability by going down 2 and to the left 2.

④



We reach the band of stability by going down and to the right.

C. Identify the three types of radioactive emissions depicted in the diagram to the right.



1 = **α-decay ($^{4}_{2}He^{2+}$)**

2 = **γ-decay (high energy, short L electromagnetic radiation)**

3 = **β-decay ($^{0}_{-1}\beta$ or $^{0}_{-1}e$)**

D. Identify which of the following statements are true for chemical reactions (CR) and those for nuclear reactions (NR).

1. _ **CR**_One substance is converted into another, but the atoms never change identity.
2. _ **CR** _Orbital electrons are involved as bonds break and form.
3. **NR** _Atoms of one element typically converted into atoms of another element.
4. _ **NR** _Protons, neutrons and other particles are involved; orbital electrons rarely take part.
5. _ **CR** _Reactions are accompanied by relatively small changes in energy and no measureable changes in mass.
6. _ **CR** _Reaction rates are influenced by temperature, concentration, catalysts and the compound in which an element occurs.
7. _ **NR** _Reactions are accompanied by large energy changes and measureable mass changes.
8. _ **NR** _Reaction rates are affected by the number of nuclei, but not by temperature, catalysts or, normally, the compound in which the element occurs.