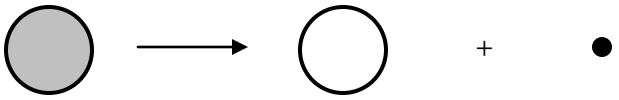
Nuclear Chemistry Worksheet #1: Nuclear Decay Processes **Name**_____
Chem 163 – K. Marr

How can one tell if a radioactive isotope undergoes alpha decay or beta decay?

The Model: Numbers of Neutrons and Protons & Beta Decay

A plot (on next page) of the number of neutrons versus the number of protons reveals to us: (1) which isotopes are known; (2) which isotopes are stable; and (3) which isotopes are radioactive. One should note the "band of stability" – the series of non-radioactive isotopes, which increases in the number of neutrons as the number of protons increases. Up through $Z = 20$ (calcium), for an isotope to be stable the number of neutrons is approximately equal to the number of protons. But as the number of protons becomes increasingly larger than 20, the number of neutrons becomes increasingly larger than the number of protons in the nucleus if it is nonradioactive. The plot may be used to predict how a radioactive isotope undergoes a nuclear reaction in order to become a stable isotope. Nuclei that lie outside the band of stability will decay in such a way so that the daughter isotope will lie on the band of stability (if possible).

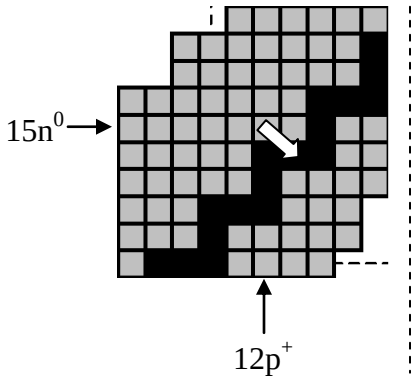
<u>Mode of Decay No. 1: Beta Decay</u>



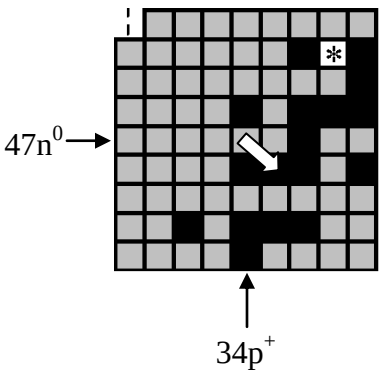
neutron in nucleus → proton in nucleus + beta particle ejected from nucleus

examples:

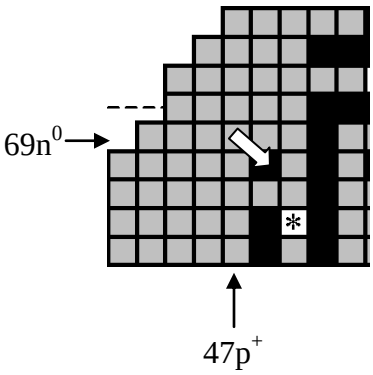
$^{27}_{12}\text{Mg} \rightarrow {}^{27}_{13}\text{Al} + {}^{0}_{-1}\text{e}$

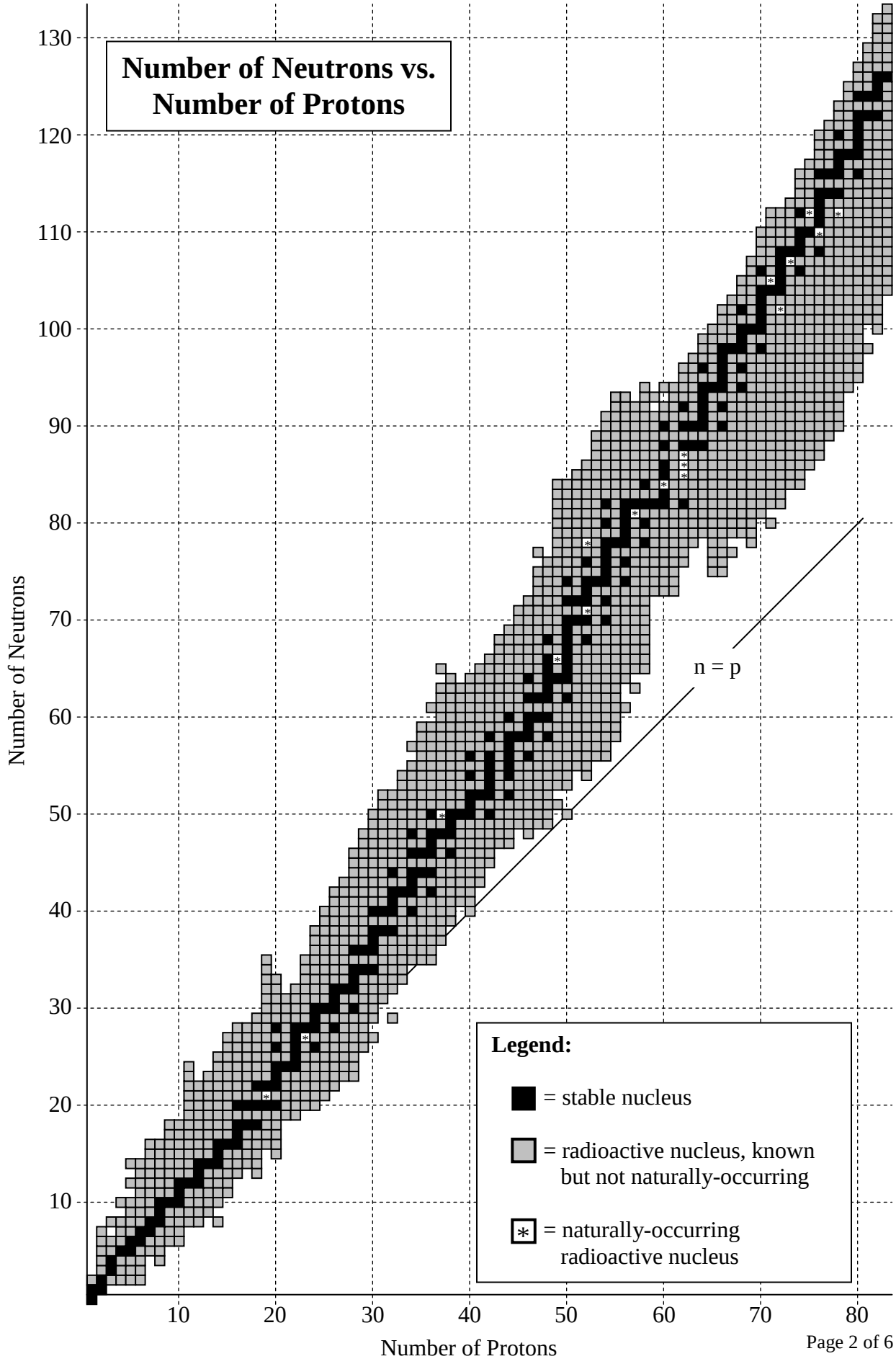


$^{81}_{34}\text{Se} \rightarrow {}^{81}_{35}\text{Br} + {}^{0}_{-1}\text{e}$



$^{116}_{47}\text{Ag} \rightarrow {}^{116}_{48}\text{Cd} + {}^{0}_{-1}\text{e}$




Number of Neutrons vs. Number of Protons
Number of Neutrons
Number of Protons
n = p
Legend:
= stable nucleus
= radioactive nucleus, known but not naturally-occurring
= naturally-occurring radioactive nucleus
10
20
30
40
50
60
70
80
90
100
110
120
130

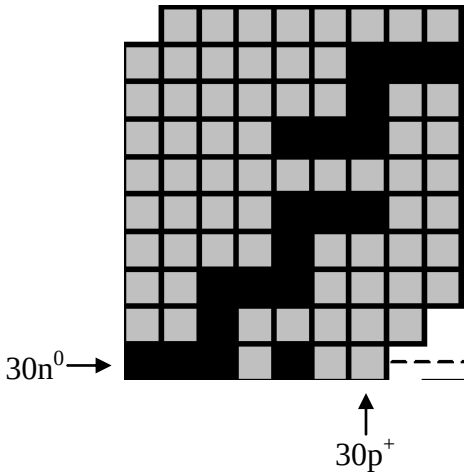
Key Questions

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?)

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?

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?

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?)



The Model: Electron Capture ("K Capture")

Mode of Decay No. 2: Electron Capture ("K Capture")

proton in nucleus — 1*s* electron "captured" by nucleus — neutron in nucleus

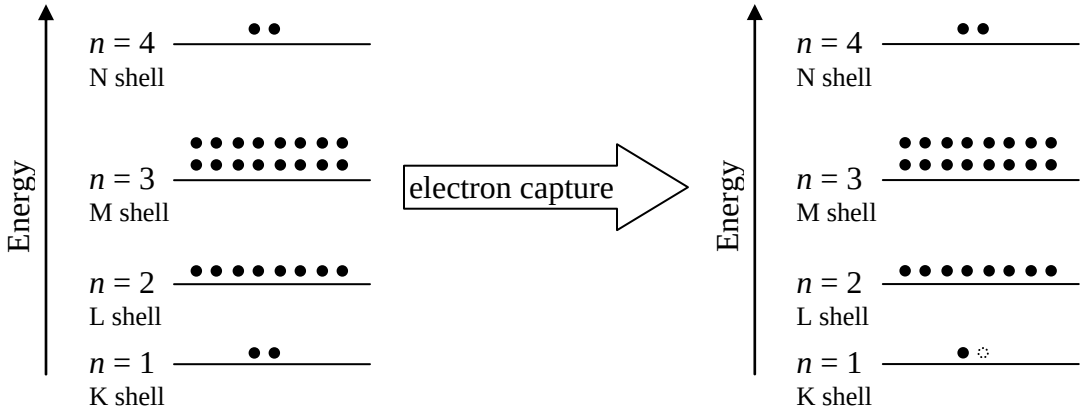
examples:

$^{55}_{26}Fe + {}^{0}_{-1}e \rightarrow {}^{55}_{25}Mn$

$^{81}_{36}Kr + {}^{0}_{-1}e \rightarrow {}^{81}_{35}Br$

Key Questions

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.

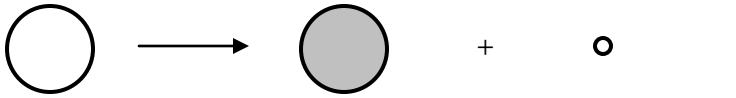
6a. When an atom's core electron is captured by the nucleus, what happens to the atomic number?

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

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 Model: Positron Emission and Alpha Decay

Mode of Decay No. 3: Positron Emission



proton in nucleus → neutron in nucleus + positron ejected from nucleus

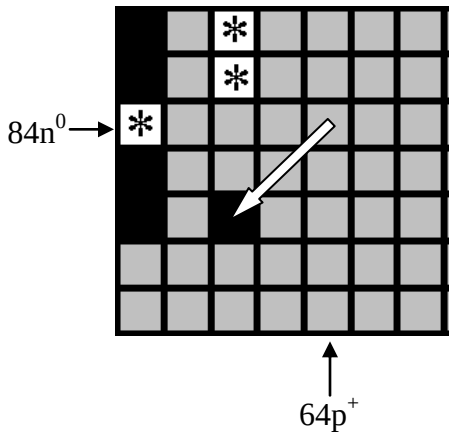
examples:

$^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + {}^{0}_{+1}\mathrm{e}$ $\qquad$ $^{80}_{37}\mathrm{Rb} \rightarrow {}^{80}_{36}\mathrm{Kr} + {}^{0}_{+1}\mathrm{e}$

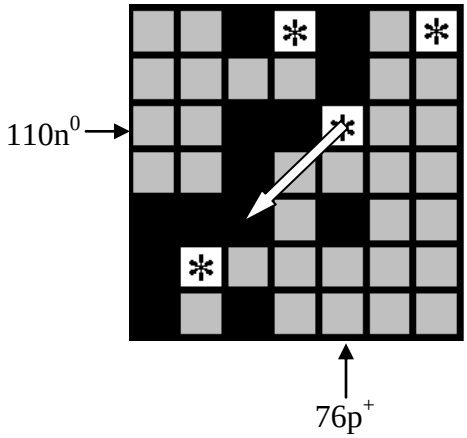
Mode of Decay No. 4: Alpha Decay

examples:

$^{148}_{64}Gd \rightarrow {}^{144}_{62}Sm +$ *alpha particle*



$^{186}_{76}Os \rightarrow {}^{182}_{74}W +$ *alpha particle*



Key Questions

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

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

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?

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.)

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

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?)

Exercises

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

① positron emission of Cs-127

② alpha decay of $^{211}_{83}Bi$

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

④ beta decay of zirconium-97

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.

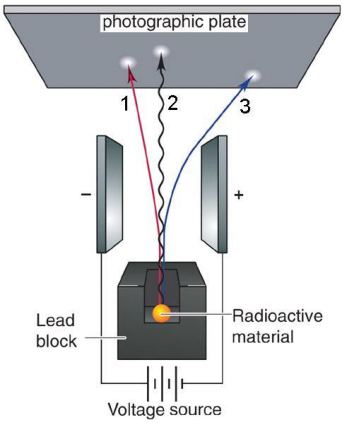
①	manganese-52	β decay	electron capture	positron emission	α decay
②	$^{203}_{82}Pb$	β decay	electron capture	positron emission	α decay
③	Be-8	β decay	electron capture	positron emission	α decay
④	antimony-126	β decay	electron capture	positron emission	α decay

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

1 = _____

2 = _____

3 = _____



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

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