Chapter 21
Nuclear Chemistry

Chapter 21–Assignment A: Natural Radioactivity: Where Does It Come From? Where Does It Go?

Most chemists study the results of electron sharing (covalent bonding, Chapters 10 and 11) and electron transfer (redox reactions, Chapter 19). Some chemists and physicists, however, study the nucleus of the atom. In the nucleus, different “rules” of synthesis and decomposition apply. In this assignment, you will study some of those new rules.

The major ideas in this assignment are:

1) Three types of natural radioactivity, alpha (α), beta (β), and gamma (γ) rays, can be formed when a nucleus decays. These rays differ in their masses, charges, and their ability to penetrate matter.

2) Radioactivity can break chemical bonds by transferring enough energy to eject bonding electrons from atoms.

3) Radioactivity can be detected by photographic film, scintillation counters, cloud chambers, or Geiger counters.

4) Each radioactive isotope possesses its own constant rate of decay.

5) The time needed for one-half the radioactive atoms in a sample to decay is the half-life of that sample. Half-life calculations can be done to determine how old a sample is, and how much is left at any time.

6) An equation for radioactive decay is balanced for nuclear charge (number of protons) and nuclear mass (number of protons and neutrons).

7) Products of radioactive decay may be other nuclei that undergo further decay, forming a natural radioactive decay sequence.

Learning Procedures

Study  
Sections 21.1–21.6. Focus on Goals 1–7 as you study.

Strategy  
Most of this material is descriptive in nature, but Goal 5 is quantitative. Instructors will vary greatly in terms of their expectations for this assignment.
Chapter 21–Assignment B: Nuclear and Chemical Reactions, Induced Radioactivity, Uses of Radioactivity

We have been able to accomplish remarkable things through nuclear change, some good, some bad. We will look into a few of these now, using these ideas:

1) Nuclear reactions differ from ordinary chemical reactions because chemical reactions involve changes in valence electrons, but nuclear reactions involve changes in the nucleus.

2) Nuclear bombardment reactions make new isotopes and elements that do not now exist in nature. These isotopes and elements can produce induced radioactivity.

3) The transuranium elements, whose atomic numbers are all greater than 92, are radioactive.

4) A nucleus that splits into lighter nuclei undergoes nuclear **fission**.

5) A **chain reaction** occurs when a product of one reaction is a reactant in the next step of the reaction pathway.

6) Two light nuclei that are joined to form a heavier nucleus undergo nuclear **fusion**.

Learning Procedures

**Study**
Sections 21.7–21.12. Focus on Goals 8–14 as you study.

**Strategy**
All of the material in this assignment is descriptive. As with Assignment A, instructors will vary in their expectations for this assignment.

**Answer**

**Workbook**
If your instructor recommends the *Active Learning Workbook*, do Questions, Exercises, and Problems 19–29.

Chapter 21–Assignment C: Summary and Review

You may think of nuclear chemistry as an untamed jungle, but there are rules to help you find the trails, just as you found the rules and trails in ordinary chemical reactions. For example, natural radioactivity has only three possible forms, as described below:
<table>
<thead>
<tr>
<th>Emission</th>
<th>Mass (amu)</th>
<th>Charge</th>
<th>Penetration of Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha ((\alpha))</td>
<td>4</td>
<td>2+</td>
<td>extremely low</td>
</tr>
<tr>
<td>beta ((\beta))</td>
<td>0</td>
<td>1–</td>
<td>low</td>
</tr>
<tr>
<td>gamma ((\gamma))</td>
<td>0</td>
<td>0</td>
<td>very high</td>
</tr>
</tbody>
</table>

Ordinary chemical reactions depend on the valence electrons outside the nucleus; nuclear reactions depend on the protons and neutrons inside the nucleus. Changes in oxidation number or chemical bonding therefore have no effect on nuclear reactions, but a great effect on ordinary chemical reactions. Different isotopes of an element undergo vastly different nuclear reactions, but these isotopes all have very similar chemical reactivities.

Is nuclear chemistry a curse or a blessing? Like all new technology, it's both. The awesome destruction of atomic (fission) and hydrogen (fusion) weapons is only too well documented. While the nightmare of nuclear Armageddon is fading, the nightmare of nuclear proliferation becomes more real. (However, the weapon of mass destruction most easily built by a third-world country is a biological or chemical weapon, not a nuclear one.) The storage of radioactive waste, including deactivated nuclear warheads, remains an unsolved political problem. The health effects of radioactive waste are a concern.

But nuclear energy does not cause acid rain, black lung disease, or greenhouse effect, all undesirable byproducts of burning natural gas, fuel oil, coal, or wood to heat homes or generate electricity. Ironically, nuclear power plants have by federal law lower radioactive emissions than coal or wood burning power plants!

The use of radionuclides by industry and medicine has made manufacturing more efficient, and therapy more healing. As an example of how nuclear chemistry affects you daily, consider the home smoke alarm. Battery powered smoke alarms depend on the radionuclide americium. No americium, no alarm.

So is nuclear chemistry a curse or a blessing? Like all tools, it depends how you wish to use it, so the answer depends on you.

**Learning Procedures**

**Review**

your lecture and textbook notes.

the Chapter in Review and the Key Terms and Concepts, and read the Study Hints and Pitfalls to Avoid.

**Answer**

Concept-Linking Exercises 1–7. Check your answers with those at the end of the chapter.

Questions, Exercises, and Problems 30–32. Include Questions 33–35 if assigned by your instructor. Check your answers with those at the end of the chapter.

**Workbook**

If your instructor recommends the *Active Learning Workbook*, do Questions, Exercises, and Problems 30–31. Include Questions 32–34 if assigned by your instructor.

**Take**

the chapter summary test that follows. Check your answers with those at the end of this assignment.
Chapter 21 Sample Test

Instructions: You may use a “clean” periodic table.

1) Which natural radioactive emission is neither attracted nor repelled by either a positive or a negative charge?
   a) alpha ray  
   b) beta ray  
   c) gamma ray  
   d) both a and b

2) Ionizing radiation has an effect on body tissue because
   a) the tissue gets a positive charge  
   b) the tissue gets a negative charge  
   c) physical changes occur  
   d) chemical changes occur

3) Geiger counter tubes operate when
   a) the gas in the tube is ionized  
   b) the gas in the tube fluoresces  
   c) supersaturated vapor condenses on the ions in the tube  
   d) a clicking sound is heard

4) What fraction of a radioisotope is left after 3 half-lives have passed?
   a) 1/27  
   b) 1/9  
   c) 1/8  
   d) 1/6  
   e) 1/3

5) In 24 hours, the mass of a radioisotope changed from 3.7 mg to 0.20 mg. Determine the half-life of this isotope. You may use Figure 21.5.

6) Balance the nuclear equation \[ ^{221}_{87}\text{Fr} \overset{\text{\square}}{\longrightarrow} \ldots + ^{4}\overset{\text{\text{He}}}{{2}} \]

7) The three natural radioactive decay sequences all end with a _____ isotope as the final product.
   a) \( ^{\text{92}}\text{U} \)  
   b) \( ^{\text{90}}\text{Th} \)  
   c) \( ^{\text{82}}\text{Pb} \)  
   d) \( ^{\text{91}}\text{Pa} \)
8) Which of the following pairs have the same chemical properties?
   a) $^{239}_{94} \text{Pu}^{4+}$ and $^{238}_{94} \text{Pu}$
   b) $^{239}_{94} \text{Pu}$ and $^{238}_{94} \text{Pu}^{4+}$
   c) $^{239}_{94} \text{Pu}^{4+}$ and $^{238}_{94} \text{Pu}^{4+}$
   d) all have the same chemical properties

9) Induced radioactivity comes from
   a) stable products of bombardment reactions
   b) background radiation
   c) radioactive products of bombardment reactions
   d) cosmic radiation

10) Which is not a transuranium element?
    a) $^{231}_{93} \text{Np}$  
    b) $^{247}_{97} \text{Bk}$
    c) $^{244}_{94} \text{Pu}$  
    d) $^{237}_{91} \text{Pa}$

The following are the answer choices for Questions 11–14:

a) $^{235}_{92} \text{U} + ^{1}_{0} \text{n} \rightarrow ^{144}_{54} \text{Xe} + ^{90}_{38} \text{Sr} + 2 ^{1}_{0} \text{n}$

b) $^{96}_{42} \text{Mo} + ^{2}_{1} \text{H} \rightarrow ^{97}_{43} \text{Tc} + ^{1}_{0} \text{n}$

c) $^{2}_{3} \text{He} + ^{3}_{2} \text{He} \rightarrow ^{4}_{2} \text{He} + 2 ^{1}_{1} \text{H}$

d) $^{20}_{8} \text{O} \rightarrow ^{20}_{9} \text{F} + ^{0}_{-1} \text{e}$

11) Which reaction above is a nuclear bombardment reaction?

12) Which reaction above is a nuclear fission reaction?

13) Which reaction above could be used in a nuclear chain reaction?

14) Which reaction above is a nuclear fusion reaction?

Answers to Chapter 21 Sample Test

1) c  
2) d  
3) a  
4) c  

5)  

\[ \frac{R}{S} = 0.20 \text{mg}/3.7 \text{mg} = 0.054 \]

From Figure 21.5, fraction remaining = 0.054 corresponds to 4.2 half-lives

\[ \frac{24 \text{ hr}}{4.2 \text{ half-lives}} = 5.7 \text{ hr/half-life} \]

6) $^{217}_{85} \text{At}$

7) c  
8) c  
9) c  
10) d  

11) b  
12) a  
13) a  
14) c