Unit 3B - Nuclear Chemistry Study Guide

1. Nuclear Radiation

I. Introduction

A. Nucleons

1. Neutrons and protons

B. Nuclides

1. Atoms identified by the number of protons and neutrons in the nucleus

a. radium-228 or $^{228}_{88}Ra$

Do This → page 664 #2 - online book, page 703 in class

II. Radioactivity

A. Radioactive Decay

1. The spontaneous disintegration of a nucleus into a slightly lighter and more stable nucleus, accompanied by emission of particles, electromagnetic radiation, or both

B. Nuclear Radiation

1. Particles or electromagnetic radiation emitted from the nucleus during radioactive decay

C. Unstable Nuclides

1. All nuclides beyond atomic # 83 are unstable and radioactive

III. Types of Radioactive Decay

A. Alpha Emission

1. Alpha particle (α) is a helium nucleus ($^{4}_{2}He$), so it has a 2+ charge.

2. Alpha emission is restricted almost entirely to very heavy nuclei

$$^{210}_{84}Po + \rightarrow ^{206}_{82}Pb + ^{4}_{2}He$$

B. Beta Emission

1. Beta particle (β) is an electron emitted from the nucleus during nuclear decay

$$^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e$$

2. Beta particles are emitted when a neutron is converted into a proton and an electron

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$$

* Do This: page 664 online or 703 in class #15

Nuclear Equations

Do This → Complete each nuclear equation by filling in the blank space. Then name the type of decay.

1. $^{214}_{84}Po \rightarrow ^{210}_{82}Pb +$ ________

2. $^{222}_{86}Rn \rightarrow$ ________ $+ ^{4}_{2}He$

3. $^{230}_{90}Th \rightarrow ^{226}_{88}Ra +$ ________

4. $^{214}_{82}Pb \rightarrow$ ________ $+ ^{0}_{-1}e$

5. $^{226}_{88}Ra \rightarrow$ ________ $+ ^{4}_{2}He$

6. $^{239}_{93}Np \rightarrow$ ________ $+ ^{0}_{-1}e$

7. ________ $\rightarrow ^{234}_{90}Th + ^{4}_{2}He$

8. $^{234}_{92}U \rightarrow ^{234}_{93}Np +$ ________

9. $^{206}_{82}Pb + ^{4}_{2}He \rightarrow$ ________

10. $^{254}_{91}Pa \rightarrow$ ________ $+ ^{0}_{-1}e$

11. $^{226}_{88}Ra \rightarrow$ ________ $+ ^{4}_{2}He$ + gamma rays

12. $^{214}_{82}Pb \rightarrow$ ________ $+ ^{0}_{-1}e$ + gamma rays

* Now Try: #42 pg. 665 - online, 704 - text book

III Transmutation Reactions

A. Transmutations

1. A change in the identity of a nucleus as a result of a change in the number of its protons

B. Nuclear Reaction

1. A reaction that affects the nucleus of an atom
2. Small amounts of mass are converted to LARGE amounts of energy
   a. $E = mc^2$

C. Balancing Nuclear Reactions

1. Total atomic numbers and mass numbers must be equal on both sides

$$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

Complete the following nuclear equations.

1. $\_\_\_\_\_ + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}p$
2. $\_\_\_\_\_ \rightarrow ^{181}_{77}Ir + ^{4}_{2}He$
3. $^{241}_{95}Am \rightarrow \_\_\_\_\_ + ^{237}_{93}Np$
4. $\_\_\_\_\_ + ^{12}_{6}C \rightarrow ^{246}_{98}Cf + 4^{1}_{0}n$
5. $^{142}_{61}Pm + \_\_\_\_\_ \rightarrow ^{142}_{60}Nd$
6. $^{14}_{7}N + \_\_\_\_\_ \rightarrow ^{14}_{6}C + ^{1}_{1}p$
7. $^{13}_{6}C + ^{1}_{0}n \rightarrow \_\_\_\_\_$
8. $^{239}_{94}Pu + ^{4}_{2}He \rightarrow ^{1}_{1}H + 2^{1}_{0}n + \_\_\_\_\_$

3. **Fission and Fusion of Atomic Nuclei**

I Nuclear Fission

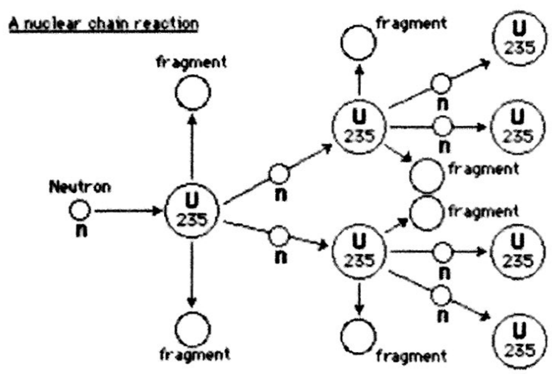
A. Nuclear Fission

1. A very heavy nucleus splits into more stable nuclei of intermediate mass
2. The mass of the products is less than the mass of the reactants. Missing mass is converted to energy
   a. Small amounts of missing mass are converted to HUGE amounts of energy ($E = mc^2$)

B. Nuclear Chain Reaction

1. A reaction in which the material that starts the reaction is also one of the products and can start another reaction

Do This → page 704 # 35+37



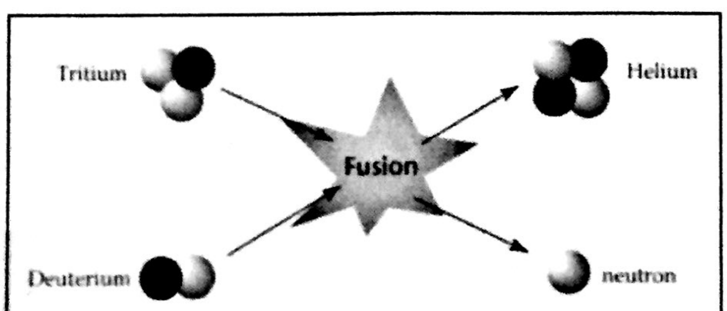
C. Critical Mass

1. The minimum amount of nuclide that provides the number of neutrons needed to sustain a chain reaction

II Nuclear Fusion

A. Nuclear Fusion

1. Light-mass nuclei combine to form a heavier, more stable nucleus Do This → page 704 #38+39



C. Gamma Emission

1. Gamma rays (γ) are high-energy electromagnetic waves emitted from a nucleus as it changes from an excited state to a ground energy state
2. Gamma rays are produced when nuclear particles undergo transitions in energy levels
3. Gamma emission usually follows other types of decay that leave the nucleus in an excited state

10^{-12}	10^{-10}	10^{-8}	4 to 7×10^{-7}	10^{-4}	10^{-2}	1	10^{2}	10^{4}
gamma	xrays	UV	visible	IR	micro	Radio waves		
						FM	short	AM

Do This → page 703 #20 in class, 664 - online book

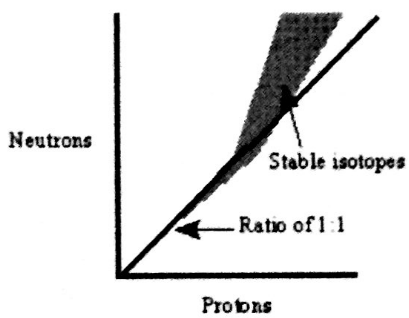
2. **Radioactive Decay**

I. Nuclear Stability and Decay

Do This → page 703 #s 9+10, 704 #44, 705 # 51 (online book page 669 to 667)

A. Neutron-to-Proton Ratio determines the type of decay that occurs

1. Band of Stability



II. Half-Life

A. Half-Life ($t_{1/2}$)

1. The time required for half the atoms of a radioactive nuclide to decay
   a. More stable nuclides decay slowly
   b. Less stable nuclides decay rapidly

Table 22-2	Representative Radioactive Nuclides and Their Half Lives		
Nuclide	*Half-life*	*Nuclide*	*Half-life*
$^{3}_{1}H$	12.32 years	$^{214}_{84}Po$	163.7 µseconds
$^{14}_{6}C$	5715 years	$^{218}_{84}Po$	3.0 minutes
$^{32}_{15}P$	14.28 days	$^{218}_{85}At$	1.6 seconds
$^{40}_{19}K$	1.3 x 109 years	$^{238}_{92}U$	4.46 x 10^{9} years
$^{60}_{27}Co$	10.47 minutes	$^{239}_{94}Pu$	2.41 x 10^{4} years

Do This → page 704 #s 41+43 +28, page 665 online text

B. Fusion Reactions

1. More energetic than fission rxns
2. Source of energy of the hydrogen bomb
3. Could produce energy for human use if a way can be found to contain a fusion rxn (magnetic field?)

4. Radiation in Your Life

A. Penetrating Ability

1. Alpha Particles
    a. Least penetrating ability due to large mass and charge
    b. Travel only a few centimeters through air
    c. Cannot penetrate skin
    d. Can cause harm through ingestion or inhalation
2. Beta Particles
    a. Travel at speeds close to the speed of light
    b. Penetrating ability about 100 times greater than that of alpha particles.
    c. They have a range of a few meters in air.
3. Gamma rays
    a. Greatest penetrating ability
    b. Protection requires shielding with thick layers of lead, cement, or both

C. Penetrating ability of radiation

Increasing penetrating ability →

ALPHA ——→ BETA ——→ GAMMA

Least harmful … most harmful

C. Radioactive Elements

1. All isotopes of all man-made elements are radioactive
2. Some naturally isotopes are radioactive
    a. All isotopes of all elements beyond bismuth (atomic #83) are radioactive

Do This: pg 704 (ws) #31

CHAPTER 21 Review

SECTION 1

The Nucleus

REVIEWING MAIN IDEAS

1. a. How does mass defect relate to nuclear binding energy?
   b. How does binding energy per nucleon vary with mass number?
   c. How does binding energy per nucleon affect the stability of a nucleus?

2. Describe three ways in which the number of protons and the number of neutrons in a nucleus affect the stability of the nucleus.

PRACTICE PROBLEMS

3. The mass of a $^{20}_{10}Ne$ atom is 19.992 44 u. Calculate the atom's mass defect.

4. The mass of a $^{7}_{3}Li$ atom is 7.016 00 u. Calculate the atom's mass defect.

5. Calculate the nuclear binding energy of one lithium-6 atom. The measured atomic mass of lithium-6 is 6.015 u.

6. Calculate the binding energies of the following two nuclei, and indicate which nucleus releases more energy when formed. You will need information from the periodic table and the text.
   a. atomic mass 34.988011 u, $^{35}_{19}K$
   b. atomic mass 22.989767 u, $^{23}_{11}Na$

7. a. What is the binding energy per nucleon for each nucleus in the previous problem?
   b. Which nucleus is more stable?

8. The mass of $^{7}_{3}Li$ is 7.016 00 u. Calculate the binding energy per nucleon for $^{7}_{3}Li$.

9. Calculate the neutron-proton ratios for the following nuclides:
   a. $^{12}_{6}C$
   b. $^{3}_{1}H$
   c. $^{206}_{82}Pb$
   d. $^{134}_{50}Sn$

10. a. Locate the nuclides in problem 9 on the graph in **Figure 1.2**. Which ones lie within the band of stability?
    b. For the stable nuclides, determine whether their neutron-proton ratio tends toward 1:1 or 1.5:1.

11. Balance the following nuclear equations. (Hint: See Sample Problem A.)
    a. $^{43}_{19}K \longrightarrow {}^{43}_{20}Ca + \underline{?}$
    b. $^{233}_{92}U \longrightarrow {}^{229}_{90}Th + \underline{?}$
    c. $^{11}_{6}C + \underline{?} \longrightarrow {}^{11}_{5}B$
    d. $^{13}_{7}N \longrightarrow + {}^{1}_{0}\beta + \underline{?}$

12. Write the nuclear equation for the release of an alpha particle by $^{210}_{84}Po$.

13. Write the nuclear equation for the release of a beta particle by $^{210}_{82}Pb$.

SECTION 2

Radioactive Decay

REVIEWING MAIN IDEAS

14. Where on the periodic table are most of the natural radioactive nuclides located?

15. What changes in atomic number and mass number occur in each of the following types of radioactive decay?
    a. alpha emission
    b. beta emission
    c. positron emission
    d. electron capture

16. Which types of radioactive decay cause the transmutation of a nuclide? (Hint: Review the definition of *transmutation.*)

17. Explain how beta emission, positron emission, and electron capture affect the neutron-proton ratio.

18. Write the nuclear reactions that show particle conversion for the following types of radioactive decay:
    a. beta emission
    b. positron emission
    c. electron capture

19. Compare electrons, beta particles, and positrons.

20. a. What are gamma rays?
    b. How do scientists think gamma rays are produced?

21. How does the half-life of a nuclide relate to the stability of the nuclide?

22. List the three parent nuclides of the natural decay series.

23. How are artificial radioactive isotopes produced?

24. Neutrons are more effective for bombarding atomic nuclei than protons or alpha particles are. Why?

25. Why are all of the transuranium elements radioactive? (Hint: See Section 1.)

PRACTICE PROBLEMS

26. The half-life of plutonium-239 is 24 110 years. Of an original mass of 100.g, how much plutonium-239 remains after 96 440 years? (Hint: See Sample Problem B.)

27. The half-life of thorium-227 is 18.72 days. How many days are required for three-fourths of a given amount of thorium-227 to decay?

28. Exactly $\frac{1}{16}$ of a given amount of protactinium-234 remains after 26.76 hours. What is the half-life of protactinium-234?

29. How many milligrams of a 15.0 mg sample of radium-226 remain after 6396 years? The half-life of radium-226 is 1599 years.

SECTION 3

Nuclear Radiation

REVIEWING MAIN IDEAS

30. Why can a radioactive material affect photographic film even though the film is completely wrapped in black paper?

31. How does the penetrating ability of gamma rays compare with that of alpha particles and beta particles?

32. How does nuclear radiation damage biological tissue?

33. Explain how film badges, Geiger-Müller counters, and scintillation detectors are used to detect radiation and measure radiation exposure.

34. How is the age of an object that contains a radioactive nuclide estimated?

SECTION 4

Nuclear Fission and Nuclear Fusion

REVIEWING MAIN IDEAS

35. How is the fission of a uranium-235 nucleus induced?

36. How does the fission of uranium-235 produce a chain reaction?

37. Describe the purposes of the five major components of a nuclear power plant.

38. Describe the reaction that produces the sun's energy.

39. What is one problem that must be overcome before controlled fusion reactions that produce energy are a reality?

Mixed Review

REVIEWING MAIN IDEAS

40. Balance the following nuclear reactions:
    a. ${}^{239}_{93}\text{Np} \longrightarrow {}^{0}_{-1}\beta + \underline{?}$
    b. ${}^{9}_{4}\text{Be} + {}^{4}_{2}\text{He} \longrightarrow \underline{?}$
    c. ${}^{32}_{15}\text{P} + \underline{?} \longrightarrow {}^{33}_{15}\text{P}$
    d. ${}^{236}_{92}\text{U} \longrightarrow {}^{94}_{36}\text{Kr} + \underline{?} + 3\,{}^{1}_{0}n$

41. After 4797 years, how much of the original 0.250 g of radium-226 remains? The half-life of radium-226 is 1599 years.

42. The parent nuclide of the thorium decay series is ${}^{232}_{90}\text{Th}$. The first four decays are as follows: alpha emission, beta emission, beta emission, and alpha emission. Write the nuclear equations for this series of emissions.

43. The half-life of radium-224 is 3.66 days. What was the original mass of radium-224 if 0.0500 g remains after 7.32 days?

44. Calculate the neutron-proton ratios for the following nuclides, and determine where they lie in relation to the band of stability.
    a. ${}^{235}_{92}\text{U}$
    b. ${}^{16}_{8}\text{O}$
    c. ${}^{56}_{26}\text{Fe}$
    d. ${}^{156}_{60}\text{Nd}$

45. Calculate the binding energy per nucleon of ${}^{238}_{92}\text{U}$ in joules. The atomic mass of a ${}^{238}_{92}\text{U}$ nucleus is 238.050 784 u.

46. The energy released by the formation of a nucleus of $^{56}_{26}Fe$ is 7.89×10^{-11} J. Use Einstein's equation, $E = mc^2$, to determine how much mass (in kilograms) is lost in this process.

47. Calculate the binding energy for one mole of deuterium atoms. The measured mass of deuterium is 2.0140 u.

CRITICAL THINKING

48. Why do we compare binding energy per nuclear particle of different nuclides instead of the total binding energy per nucleus of different nuclides?

49. Why is the constant rate of decay of radioactive nuclei so important in radioactive dating?

50. Which of the following nuclides of carbon is more likely to be stable? State reasons for your answer.
   a. $^{11}_{6}C$ **b.** $^{12}_{6}C$

51. Which of the following nuclides of iron is more likely to be stable? State reasons for your answer.
   a. $^{56}_{26}Fe$ **b.** $^{59}_{26}Fe$

52. Use the data shown below to determine the following:
   a. the isotopes that would be best for dating ancient rocks
   b. the isotopes that could be used as tracers

   State reasons for your answers.

Element	Half-Life
potassium-40	1.28×10^9 y
potassium-42	12.36 h
uranium-238	4.468×10^9 y
uranium-239	23.47 min

RESEARCH AND WRITING

53. Investigate the history of the Manhattan Project.

54. Research the 1986 nuclear reactor accident at Chernobyl, Ukraine. What factors combined to cause the accident?

55. Find out about the various fusion-energy research projects that are being conducted in the United States and other parts of the world. What obstacles in finding an economical method of producing energy must still be overcome?

ALTERNATIVE ASSESSMENT

56. Using the library, research the medical uses of radioactive isotopes such as cobalt-60 and technetium-99. Evaluate the benefits and risks of using radioisotopes in the diagnosis and treatment of medical conditions. Report your findings to the class.