24.E: Nuclear Chemistry (Exercises)

A general chemistry Libretexts Textmap organized around the textbook

Chemistry: Principles, Patterns, and Applications

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These are homework exercises to accompany the Textmap created for "Chemistry: Principles, Patterns, and Applications" by Bruce A. Averill and Patricia Eldredge. Complementary General Chemistry question banks can be found for other Textmaps and can be accessed here. In addition to these publicly available questions, access to private problems bank for use in exams and homework is available to faculty only on an individual basis; please contact Delmar Larsen for an account with access permission.

20.1: Components of the Nucleus

Conceptual Problems

1. What distinguishes a nuclear reaction from a chemical reaction? Use an example of each to illustrate the differences.

2. What do chemists mean when they say a substance is *radioactive*?

3. What characterizes an isotope? How is the mass of an isotope of an element related to the atomic mass of the element shown in the periodic table?

4. In a typical nucleus, why does electrostatic repulsion between protons not destabilize the nucleus? How does the neutron-to-proton ratio affect the stability of an isotope? Why are all isotopes with $Z > 83$ unstable?

5. What is the significance of a *magic number* of protons or neutrons? What is the relationship between the number of stable isotopes of an element and whether the element has a magic number of protons?

6. Do you expect Bi to have a large number of stable isotopes? Ca? Explain your answers.

7. Potassium has three common isotopes, ^{39}K, ^{40}K, and ^{41}K, but only potassium-40 is radioactive (a beta emitter). Suggest a reason for the instability of ^{40}K.

8. Samarium has 11 relatively stable isotopes, but only 4 are nonradioactive. One of these 4 isotopes is ^{144}Sm, which has a lower neutron-to-proton ratio than lighter, radioactive isotopes of samarium. Why is ^{144}Sm more stable?

Answers

5. Isotopes with magic numbers of protons and/or neutrons tend to be especially stable. Elements with magic numbers of protons tend to have more stable isotopes than elements that do not.

7. Potassium-40 has 19 protons and 21 neutrons. Nuclei with odd numbers of both protons and neutrons tend to be unstable. In addition, the neutron-to-proton ratio is very low for an element with this mass, which decreases nuclear stability.

Numerical Problems

1. Write the nuclear symbol for each isotope using $^{A}_{Z}$X notation.

   a. chlorine-39

   b. lithium-8

   c. osmium-183

   d. zinc-71

2.Write the nuclear symbol for each isotope using $^{A}_{Z}$X notation.

a. lead-212

b. helium-5

c. oxygen-19

d. plutonium-242

3. Give the number of protons, the number of neutrons, and the neutron-to-proton ratio for each isotope.

a. iron-57

b. ^{185}W

c. potassium-39

d. ^{131}Xe

4. Give the number of protons, the number of neutrons, and the neutron-to-proton ratio for each isotope.

a. technetium-99*m*

b. ^{140}La

c. radium-227

d. ^{208}Bi

5. Which of these nuclides do you expect to be radioactive? Explain your reasoning.

a. ^{20}Ne

b. tungsten-184

c. ^{106}Ti

6. Which of these nuclides do you expect to be radioactive? Explain your reasoning.

a. ^{107}Ag

b. ^{50}V

c. lutetium-176

Answers

1.

a. $^{39}_{17}Cl$

b. $^{8}_{3}Li$

c. $^{183}_{76}Os$

d. $^{71}_{30}Zn$

3.

a. 26 protons; 31 neutrons; 1.19

b. 74 protons; 111 neutrons; 1.50

c. 19 protons; 20 neutrons; 1.05

d. 54 protons; 77 neutrons; 1.43

20.2: Nuclear Reactions

Conceptual Problems

1. Describe the six classifications of nuclear decay reactions. What is the most common mode of decay for elements that have heavy nuclei? Why?
2. Complete the following table for these five nuclear reactions.

	Alpha Decay	Beta Decay	Gamma Emission	Positron Emission	Electron Capture
identity of particle or radiation	helium-4 nucleus				
mass number of parent − mass number of daughter	4				
atomic number of parent − atomic number of daughter		−1			
effect on neutron-to-proton ratio		decreases			

3. What is the most common decay process for elements in row 5 of the periodic table that contain too few neutrons for the number of protons present? Why?
4. Explain the difference between the symbols e^- and β^-. What is the difference in meaning between the symbols ${}^4_2He$ and ${}^4_2\alpha$?
5. What is a mass number? Which particles have a mass number of zero?
6. What are the key differences between the equations written for chemical reactions and for nuclear reactions? How are they similar?
7. Can all the kinds of nuclear decay reactions discussed be characterized by the general equation: parent → daughter + particle? Explain your answer.
8. Which types of nuclear decay reactions conserve both mass number and atomic number? In which do the parent and daughter nuclei have the same mass number but different atomic numbers? Which do not convert one element to another?
9. Describe a radioactive decay series. How many series occur naturally? Of these, which one no longer occurs in nature? Why?
10. Primordial nuclides are nuclides found on Earth that have existed in their current form since before Earth was formed. Primordial nuclides are residues from the Big Bang, from cosmogenic sources, and from ancient supernova explosions which occurred before the formation of the Solar System. Only four primordial nuclides with atomic numbers greater than lead (Z>82)) still exist (${}^{209}Bi$, ${}^{232}Th$, ${}^{235}U$, and ${}^{238}U$) - and all of them are radioactive. Except for some isotopes of thorium and uranium that have a very long half-life, the half-lives of the heavy elements are so short that these elements should have been completely converted to lighter, more stable elements long ago. Why are these elements still present in nature?
11. Why are neutrons preferred to protons when preparing new isotopes of the lighter elements?
12. Why are particle accelerators and cyclotrons needed to create the transuranium elements?

Answers

3. Both positron decay and electron capture increase the neutron-to-proton ratio; electron capture is more common for heavier elements such those of row 5.

5. The mass number is the sum of the numbers of protons and neutrons present. Particles with a mass number of zero include β particles (electrons) and positrons; gamma rays and x-rays also have a mass number of zero.

11. Unlike protons, neutrons have no charge, which minimizes the electrostatic barrier to colliding and reacting with a positively charged nucleus.

Numerical Problems

1. What type of particle is emitted in each nuclear reaction?
   a. ${}^{238}Pu \rightarrow {}^{234}U$
   b. ${}^{32}Si \rightarrow {}^{32}P$
   c. ${}^{18}F \rightarrow {}^{18}O$
   d. ${}^{206}Tl \rightarrow {}^{206}Pb$

2. What type of particle is emitted in each nuclear reaction?
   a. ${}^{230}Th \rightarrow {}^{226}Ra$

b. $^{224}Rn \rightarrow {}^{224}Fr$
c. $^{210}Bi \rightarrow {}^{206}Tl$
d. $^{36}Cl \rightarrow {}^{36}S$

3. Predict the mode of decay and write a balanced nuclear reaction for each isotope.
   a. ^{235}U
   b. ^{254}Es
   c. ^{36}S
   d. ^{99}Mo

4. Predict the mode of decay and write a balanced nuclear reaction for each isotope.
   a. ^{13}N
   b. ^{231}Pa
   c. ^{7}Be
   d. ^{77}Ge

5. Balance each nuclear reaction.
   a. $^{208}Po \rightarrow \alpha + Pb$
   b. $^{226}Ra \rightarrow \alpha + Rn$
   c. $^{228}Th \rightarrow Ra + \alpha + \gamma$
   d. $^{231}Pa \rightarrow Ac + \alpha + \gamma$
   e. $Ho \rightarrow {}^{166}Er + \beta^- + \gamma$
   f. $Ac \rightarrow {}^{226}Th + \beta^- + \gamma$

6. Complete each nuclear reaction.
   a. $^{210}_{84}Po \rightarrow {}^{206}Pb$
   b. $^{217}_{85}At \rightarrow Bi + \alpha$
   c. $Ra \rightarrow^{220}_{86} Rn + \alpha$
   d. $^{208}Tl \rightarrow {}^{82}Pb + \beta^-$
   e. $Np \rightarrow {}^{239}Pu + \beta^-$
   f. $Fe \rightarrow {}^{52}Mn + \beta^+ + \gamma$

7. Write a balanced nuclear equation for each reaction.
   a. β^- decay of ^{87}Rb
   b. β^+ decay of ^{20}Mg
   c. α decay of ^{268}Mt

8. Write a balanced nuclear equation for each reaction.
   a. β^- decay of ^{45}K
   b. β^+ decay of ^{41}Sc
   c. α decay of ^{146}Sm

9. The decay products of several isotopes are listed here. Identify the type of radiation emitted and write a balanced nuclear equation for each.
   a. $^{218}Po \rightarrow {}^{214}Pb$
   b. $^{32}Si \rightarrow {}^{32}P$
   c. an excited state of an iron-57 nucleus decaying to its ground state
   d. conversion of thallium-204 to lead-204

10. The decay products of several isotopes are listed here. Identify the type of radiation emitted and write a balanced nuclear equation for each.
   a. $^{218}Po \rightarrow {}^{218}At$
   b. $^{216}Po \rightarrow {}^{212}Pb$
   c. bismuth-211 converted to thallium-207
   d. americium-242 converted to rhodium-107 with the emission of four neutrons

11. Predict the most likely mode of decay and write a balanced nuclear reaction for each isotope.
    a. ^{238}U
    b. ^{208}Po
    c. ^{40}S
    d. molybdenum-93m

12. Predict the most likely mode of decay and write a balanced nuclear reaction for each isotope.
    a. ^{16}N
    b. ^{224}Th
    c. ^{118}In
    d. ^{64}Ge

13. For each nuclear reaction, identify the type(s) of decay and write a balanced nuclear equation.
    a. $^{216}Po \rightarrow ? + At$
    b. $? \rightarrow \alpha + {}^{231}Pa$
    c. $^{228}Th \rightarrow ? + \alpha + \gamma$
    d. $^{231}Pa \rightarrow ? + \beta^- + \gamma$

14. For each nuclear reaction, identify the type(s) of decay and write a balanced nuclear equation.
    a. $^{212}Po \rightarrow {}^{208}Pb + ?$
    b. $^{192}Ir \rightarrow Pt + ?$
    c. $^{241}Am \rightarrow {}^{57}Fe + {}^{184}? + ?$
    d. $Ge \rightarrow {}^{77}Ge + ?$

15. Identify the parent isotope and write a balanced nuclear reaction for each process.
    a. Lead-205 is formed via an alpha emission.
    b. Titanium-46 is formed via beta and gamma emission.
    c. Argon-36 is formed via a beta decay and a gamma emission.

16. Identify the parent isotope and write a balanced nuclear reaction for each process.
    a. Iodine-130 is formed by ejecting an electron and a gamma ray from a nucleus.
    b. Uranium-240 is formed by alpha decay.
    c. Curium-247 is formed by releasing a helium dication and a gamma ray.

17. Write a balanced nuclear equation for each process.
    a. Bromine undergoes a decay and produces a gas with an atomic mass of 80 amu.
    b. An element emits two neutrons while decaying into two metals, each of which can be extracted and converted to chlorides with the formula MCl_2. The masses of the two salts are 162.9 and 210.9 g/mol, respectively.

18. Write a balanced nuclear equation for each process.
    a. An unknown element emits γ rays plus particles that are readily blocked by paper. The sample also contains a substantial quantity of tin-104.
    b. An unstable element undergoes two different decay reactions: beta decay to produce a material with a mass of 222 amu and alpha decay to astatine.

19. Bombarding ^{249}Cf with ^{12}C produced a transuranium element with a mass of 257 amu, plus several neutral subatomic particles. Identify the element and write a nuclear reaction for this transmutation.

20. One transuranium element, ^{253}Es, is prepared by bombarding ^{238}U with 15 neutrons. What is the other product of this reaction? Write a balanced transmutation reaction for this conversion.

21. Complete this radioactive decay series:

$$^{223}_{88}\mathrm{Ra} \xrightarrow{\alpha} \mathrm{Rn} \xrightarrow{\alpha} \mathrm{Po} \xrightarrow{\alpha} \mathrm{Pb} \xrightarrow{\beta^-} \mathrm{Bi} \xrightarrow{\alpha} \mathrm{Tl} \xrightarrow{\beta^-} \mathrm{Pb}$$

22. Complete each nuclear fission reaction.
    a. $^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{90}_{36}\mathrm{Kr} + ? + 2{}^{1}_{0}\mathrm{n}$
    b. $? + {}^{1}_{0}\mathrm{n} \rightarrow {}^{140}\mathrm{Cs} + {}^{96}\mathrm{Y} + 4{}^{1}_{0}\mathrm{n}$

23. Complete each nuclear fission reaction.
    a. $^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{145}_{57}\mathrm{La} + ? + 3^{1}_{0}\mathrm{n}$
    b. $? + ^{1}_{0}\mathrm{n} \rightarrow ^{95}_{42}\mathrm{Mo} + ^{139}_{57}\mathrm{La} + 2^{1}_{0}\mathrm{n} + 7^{0}_{-1}\beta$
24. A stable nuclide absorbs a neutron, emits an electron, and then splits into two α particles. Identify the nuclide.
25. Using ^{18}O, how would you synthesize an element with atomic number 106 from ^{249}Cf? Write a balanced nuclear equation for the reaction.
26. Using ^{10}B and ^{252}Cf, how would you synthesize an element with atomic number 103? Write a balanced nuclear equation for the reaction.

Answers

3. a. α decay; $^{235}_{92}\mathrm{U} \rightarrow ^{4}_{2}\alpha + ^{231}_{90}\mathrm{Th}$
   b. α decay; $^{254}_{99}\mathrm{Es} \rightarrow ^{4}_{2}\alpha + ^{250}_{97}\mathrm{Bk}$
   c. β decay; $^{36}_{16}\mathrm{S} \rightarrow ^{0}_{-1}\beta + ^{36}_{17}\mathrm{Cl}$
   d. β decay; $^{99}_{42}\mathrm{Mo} \rightarrow ^{0}_{-1}\beta + ^{99m}_{43}\mathrm{Tc}$

5.
   a. $^{208}_{84}\mathrm{Po} \rightarrow ^{4}_{2}\alpha + ^{204}_{82}\mathrm{Pb}$
   b. $^{226}_{88}\mathrm{Ra} \rightarrow ^{4}_{2}\alpha + ^{222}_{86}\mathrm{Rn}$
   c. $^{228}_{90}\mathrm{Th} \rightarrow ^{224}_{88}\mathrm{Ra} + ^{4}_{2}\alpha + \gamma$
   d. $^{231}_{91}\mathrm{Pa} \rightarrow ^{227}_{89}\mathrm{Ac} + ^{4}_{2}\alpha + \gamma$
   e. $^{166}_{67}\mathrm{Ho} \rightarrow ^{166}_{68}\mathrm{Er} + ^{0}_{-1}\beta + \gamma$
   f. $^{226}_{89}\mathrm{Ac} \rightarrow ^{226}_{90}\mathrm{Th} + ^{0}_{-1}\beta + \gamma$

7.
   a. $^{87}_{37}\mathrm{Rb} \rightarrow ^{87}_{38}\mathrm{Sr} + ^{0}_{-1}\beta$
   b. $^{20}_{12}\mathrm{Mg} \rightarrow ^{20}_{11}\mathrm{Na} + ^{0}_{-1}\beta$
   c. $^{268}_{109}\mathrm{Mt} \rightarrow ^{4}_{2}\alpha + ^{264}_{107}\mathrm{Bh}$

9.
   a. α particle; $^{218}_{84}\mathrm{Po} \rightarrow ^{4}_{2}\alpha + ^{214}_{82}\mathrm{Pb}$
   b. β particle; $^{32}_{14}\mathrm{Si} \rightarrow ^{0}_{-1}\beta + ^{32}_{15}\mathrm{P}$
   c. γ ray; $^{57m}_{26}\mathrm{Fe} \rightarrow ^{57}_{26}\mathrm{Fe} + \gamma$
   d. β particle; $^{204}_{81}\mathrm{Tl} \rightarrow ^{0}_{-1}\beta + ^{204}_{82}\mathrm{Pb}$

11.
   a. α emission; $^{238}_{92}\mathrm{U} \rightarrow ^{4}_{2}\alpha + ^{234}_{90}\mathrm{Th}$
   b. α emission; $^{208}_{84}\mathrm{Po} \rightarrow ^{204}_{82}\mathrm{Pb} + ^{4}_{2}\alpha$
   c. β emission; $^{40}_{16}\mathrm{S} \rightarrow ^{0}_{-1}\beta + ^{40}_{17}\mathrm{Cl}$
   d. γ emission; $^{93m}_{42}\mathrm{Mo} \rightarrow ^{93}_{42}\mathrm{Mo} + \gamma$

13.
   a. β decay; $^{216}_{84}\mathrm{Po} \rightarrow ^{0}_{-1}\beta + ^{216}_{85}\mathrm{At}$
   b. α decay; $^{235}_{93}\mathrm{Np} \rightarrow ^{4}_{2}\alpha + ^{231}_{91}\mathrm{Pa}$
   c. α decay; γ emission; $^{228}_{90}\mathrm{Th} \rightarrow ^{224}_{88}\mathrm{Ra} + ^{4}_{2}\alpha + \gamma$
   d. β decay, γ emission; $^{231}_{91}\mathrm{Pa} \rightarrow ^{231}_{92}\mathrm{U} + ^{0}_{-1}\beta + \gamma$

17.
   a. $^{80}_{35}\mathrm{Br} \rightarrow ^{80}_{36}\mathrm{Kr} + ^{0}_{-1}\beta$
   b. $^{234}_{94}\mathrm{Pu} \rightarrow ^{140}_{56}\mathrm{Ba} + ^{92}_{38}\mathrm{Sr} + 2^{1}_{0}\mathrm{n}$

19. $^{249}_{98}\mathrm{Cf} + ^{12}_{6}\mathrm{C} \rightarrow ^{257}_{104}\mathrm{Rf} + 4^{1}_{0}\mathrm{n}$

23.

a. $^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{145}_{57}\mathrm{La} + ^{88}_{35}\mathrm{Br} + 3^{1}_{0}\mathrm{n}$
b. $^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{95}_{42}\mathrm{Mo} + ^{139}_{57}\mathrm{La} + 2^{1}_{0}\mathrm{n} + 7^{0}_{-1}\beta$

20.3: The Interaction of Nuclear Radiation with Matter

Conceptual Problems

1. Why do scientists believe that hydrogen is the building block of all other elements? Why do scientists believe that helium-4 is the building block of the heavier elements?
2. How does a star produce such enormous amounts of heat and light? How are elements heavier than Ni formed?
3. Propose an explanation for the observation that elements with even atomic numbers are more abundant than elements with odd atomic numbers.
4. During the lifetime of a star, different reactions that form different elements are used to power the fusion furnace that keeps a star "lit." Explain the different reactions that dominate in the different stages of a star's life cycle and their effect on the temperature of the star.
5. A line in a popular song from the 1960s by Joni Mitchell stated, "We are stardust…." Does this statement have any merit or is it just poetic? Justify your answer.
6. If the laws of physics were different and the primary element in the universe were boron-11 (Z = 5), what would be the next four most abundant elements? Propose nuclear reactions for their formation.

Answer

1.
2.
3. The raw material for all elements with $Z > 2$ is helium (Z = 2), and fusion of helium nuclei will always produce nuclei with an even number of protons.
4.
5.
6.

Numerical Problems

1. Write a balanced nuclear reaction for the formation of each isotope.
   1. ^{27}Al from two ^{12}C nuclei
   2. ^{9}Be from two ^{4}He nuclei
2. At the end of a star's life cycle, it can collapse, resulting in a supernova explosion that leads to the formation of heavy elements by multiple neutron-capture events. Write a balanced nuclear reaction for the formation of each isotope during such an explosion.
   1. ^{106}Pd from nickel-58
   2. selenium-79 from iron-56
3. When a star reaches middle age, helium-4 is converted to short-lived beryllium-8 (mass = 8.00530510 amu), which reacts with another helium-4 to produce carbon-12. How much energy is released in each reaction (in megaelectronvolts)? How many atoms of helium must be "burned" in this process to produce the same amount of energy obtained from the fusion of 1 mol of hydrogen atoms to give deuterium?

20.4: Thermodynamic Stability of the Atomic Nucleus

Conceptual Problems

1. How do chemical reactions compare with nuclear reactions with respect to mass changes? Does either type of reaction violate the law of conservation of mass? Explain your answers.
2. Why is the amount of energy released by a nuclear reaction so much greater than the amount of energy released by a chemical reaction?

3. Explain why the mass of an atom is less than the sum of the masses of its component particles.
4. The stability of a nucleus can be described using two values. What are they, and how do they differ from each other?
5. In the days before true chemistry, ancient scholars (alchemists) attempted to find the philosopher's stone, a material that would enable them to turn lead into gold. Is the conversion of Pb → Au energetically favorable? Explain why or why not.
6. Describe the energy barrier to nuclear fusion reactions and explain how it can be overcome.
7. Imagine that the universe is dying, the stars have burned out, and all the elements have undergone fusion or radioactive decay. What would be the most abundant element in this future universe? Why?
8. Numerous elements can undergo fission, but only a few can be used as fuels in a reactor. What aspect of nuclear fission allows a nuclear chain reaction to occur?
9. How are transmutation reactions and fusion reactions related? Describe the main impediment to fusion reactions and suggest one or two ways to surmount this difficulty.

Numerical Problems

1. Using the information provided in Chapter 33, complete each reaction and calculate the amount of energy released from each in kilojoules.
   a. $^{238}\text{Pa} \rightarrow ? + \beta^-$
   b. $^{216}\text{Fr} \rightarrow ? + \alpha$
   c. $^{199}\text{Bi} \rightarrow ? + \beta^+$

2. Using the information provided in Chapter 33, complete each reaction and calculate the amount of energy released from each in kilojoules.
   a. $^{194}\text{Tl} \rightarrow ? + \beta^+$
   b. $^{171}\text{Pt} \rightarrow ? + \alpha$
   c. $^{214}\text{Pb} \rightarrow ? + \beta^-$

3. Using the information provided in Chapter 33, complete each reaction and calculate the amount of energy released from each in kilojoules per mole.
   a. ${}^{234}_{91}\text{Pa} \rightarrow ? + {}^{0}_{-1}\beta$
   b. ${}^{226}_{88}\text{Ra} \rightarrow ? + {}^{4}_{2}\alpha$

4. Using the information provided in Chapter 33, complete each reaction and then calculate the amount of energy released from each in kilojoules per mole.
   a. ${}^{60}_{27}\text{Co} \rightarrow ? + {}^{0}_{-1}\beta$ (The mass of cobalt-60 is 59.933817 amu.)
   b. technicium-94 (mass = 93.909657 amu) undergoing fission to produce chromium-52 and potassium-40

5. Using the information provided in Chapter 33, predict whether each reaction is favorable and the amount of energy released or required in megaelectronvolts and kilojoules per mole.
   a. the beta decay of bismuth-208 (mass = 207.979742 amu)
   b. the formation of lead-206 by alpha decay

6. Using the information provided, predict whether each reaction is favorable and the amount of energy released or required in megaelectronvolts and kilojoules per mole.
   a. alpha decay of oxygen-16
   b. alpha decay to produce chromium-52

7. Calculate the total nuclear binding energy (in megaelectronvolts) and the binding energy per nucleon for ^{87}Sr if the measured mass of ^{87}Sr is 86.908877 amu.
8. Calculate the total nuclear binding energy (in megaelectronvolts) and the binding energy per nucleon for ^{60}Ni.
9. The experimentally determined mass of ^{53}Mn is 52.941290 amu. Find each of the following.
   a. the calculated mass
   b. the mass defect
   c. the nuclear binding energy
   d. the nuclear binding energy per nucleon

10. The experimentally determined mass of ^{29}S is 28.996610 amu. Find each of the following.
    a. the calculated mass
    b. the mass defect
    c. the nuclear binding energy
    d. the nuclear binding energy per nucleon
11. Calculate the amount of energy that is released by the neutron-induced fission of ^{235}U to give ^{141}Ba, ^{92}Kr (mass = 91.926156 amu), and three neutrons. Report your answer in electronvolts per atom and kilojoules per mole.
12. Calculate the amount of energy that is released by the neutron-induced fission of ^{235}U to give ^{90}Sr, ^{143}Xe, and three neutrons. Report your answer in electronvolts per atom and kilojoules per mole.
13. Calculate the amount of energy released or required by the fusion of helium-4 to produce the unstable beryllium-8 (mass = 8.00530510 amu). Report your answer in kilojoules per mole. Do you expect this to be a spontaneous reaction?
14. Calculate the amount of energy released by the fusion of ^{6}Li and deuterium to give two helium-4 nuclei. Express your answer in electronvolts per atom and kilojoules per mole.
15. How much energy is released by the fusion of two deuterium nuclei to give one tritium nucleus and one proton? How does this amount compare with the energy released by the fusion of a deuterium nucleus and a tritium nucleus, which is accompanied by ejection of a neutron? Express your answer in megaelectronvolts and kilojoules per mole. Pound for pound, which is a better choice for a fusion reactor fuel mixture?

Answers

1.
    a. $^{238}_{91}\text{Pa} \rightarrow {}^{238}_{92}\text{U} + {}^{0}_{-1}\beta$; −5.540 × 10^{-16} kJ
    b. $^{216}_{87}\text{Fr} \rightarrow {}^{212}_{85}\text{At} + {}^{4}_{2}\alpha$; −1.470 × 10^{-15} kJ
    c. $^{199}_{83}\text{Bi} \rightarrow {}^{199}_{82}\text{Pb} + {}^{0}_{+1}\beta$; −5.458 × 10^{-16} kJ

3.
    a. $^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\beta$; 2.118 × 10^{8} kJ/mol
    b. $^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\alpha$; 4.700 × 10^{8} kJ/mol

5.
    a. The beta decay of bismuth-208 to polonium is endothermic (ΔE = 1.400 MeV/atom, 1.352 × 10^{8} kJ/mol).
    b. The formation of lead-206 by alpha decay of polonium-210 is exothermic (ΔE = −5.405 MeV/atom, −5.218 × 10^{8} kJ/mol).

7. 757 MeV/atom, 8.70 MeV/nucleon

9.
    a. 53.438245 amu
    b. 0.496955 amu
    c. 463 MeV/atom
    d. 8.74 MeV/nucleon

11. −173 MeV/atom; 1.67 × 10^{10} kJ/mol

13. ΔE = + 9.0 × 10^{6} kJ/mol beryllium-8; no

15. D–D fusion: ΔE = −4.03 MeV/tritium nucleus formed = −3.89 × 10^{8} kJ/mol tritium; D–T fusion: ΔE = −17.6 MeV/tritium nucleus = −1.70 × 10^{9} kJ/mol; D–T fusion

20.5: Applied Nuclear Chemistry

Conceptual Problems

1. In nuclear reactors, two different but interrelated factors must be controlled to prevent a mishap that could cause the release of unwanted radiation. How are these factors controlled?
2. What are the three principal components of a nuclear reactor? What is the function of each component?

3. What is meant by the term enrichment with regard to uranium for fission reactors? Why does the fuel in a conventional nuclear reactor have to be “enriched”?
4. The plot in a recent spy/action movie involved the threat of introducing stolen “weapons-grade” uranium, which consists of 93.3% ^{235}U, into a fission reactor that normally uses a fuel containing about 3% ^{235}U. Explain why this could be catastrophic.
5. Compare a heavy-water reactor with a light-water reactor. Why are heavy-water reactors less widely used? How do these two reactor designs compare with a breeder reactor?
6. Conventional light-water fission reactors require enriched fuel. An alternative reactor is the so-called heavy-water reactor. The components of the two different reactors are the same except that instead of using water (H_2O), the moderator in a heavy-water reactor is D_2O, known as “heavy water.” Because D_2O is more efficient than H_2O at slowing neutrons, heavy-water reactors do not require fuel enrichment to support fission. Why is D_2O more effective at slowing neutrons, and why does this allow unenriched fuels to be used?
7. Isotopes emit γ rays in random directions. What difficulties do these emissions present for medical imaging? How are these difficulties overcome?
8. If you needed to measure the thickness of 1.0 mm plastic sheets, what type of radiation would you use? Would the radiation source be the same if you were measuring steel of a similar thickness? What is your rationale? Would you want an isotope with a long or short half-life for this device?

Answers

1. Neutron flow is regulated by using control rods that absorb neutrons, whereas the speed of the neutrons produced by fission is controlled by using a moderator that slows the neutrons enough to allow them to react with nearby fissile nuclei.

7. It is difficult to pinpoint the exact location of the nucleus that decayed. In contrast, the collision of a positron with an electron causes both particles to be annihilated, and in the process, two gamma rays are emitted in opposite directions, which makes it possible to identify precisely where a positron emitter is located and to create detailed images of tissues.

Numerical Problems

1. Palladium-103, which decays via electron capture and emits x-rays with an energy of 3.97×10^{-2} MeV, is often used to treat prostate cancer. Small pellets of the radioactive metal are embedded in the prostate gland. This provides a localized source of radiation to a very small area, even though the tissue absorbs only about 1% of the x-rays. Due to its short half-life, all of the palladium will decay to a stable isotope in less than a year. If a doctor embeds 50 pellets containing 2.50 mg of ^{103}Pd in the prostate gland of a 73.9 kg patient, what is the patient’s radiation exposure over the course of a year?
2. Several medical treatments use cobalt-60m, which is formed by bombarding cobalt with neutrons to produce a highly radioactive gamma emitter that undergoes 4.23×10^{16} emissions/(s·kg) of pure cobalt-60. The energy of the gamma emission is 5.86×10^{-2} MeV. Write the balanced nuclear equation for the formation of this isotope. Is this a transmutation reaction? If a 55.3 kg patient received a 0.50 s exposure to a 0.30 kg cobalt-60 source, what would the exposure be in rads? Predict the potential side effects of this dose.

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