

## 14.E: Nuclear Chemistry (Exercises)

### 14.2: Radioactivity

1. Define *radioactivity*.
2. Give an example of a radioactive element. How do you know if it is radioactive?
3. How many protons and neutrons are in each isotope?
  - a.  $^{11}_5\text{B}$
  - b.  $^{27}_{13}\text{Al}$
  - c.  $^{56}_{26}\text{Fe}$
  - d.  $^{224}_{86}\text{Rn}$
4. How many protons and neutrons are in each isotope?
  - a.  $^2_1\text{H}$
  - b.  $^{112}_{48}\text{Cd}$
  - c.  $^{252}_{99}\text{Es}$
  - d.  $^{40}_{19}\text{K}$
5. Describe an alpha particle. What nucleus is it equivalent to?
6. Describe a beta particle. What subatomic particle is it equivalent to?
7. What are gamma rays?
8. Why is it inappropriate to refer to gamma rays as “gamma particles”?
9. Plutonium has an atomic number of 94. Write the nuclear equation for the alpha particle emission of plutonium-244. What is the daughter isotope?
10. Francium has an atomic number of 87. Write the nuclear equation for the alpha particle emission of francium-212. What is the daughter isotope?
11. Tin has an atomic number of 50. Write the nuclear equation for the beta particle emission of tin-121. What is the daughter isotope?
12. Technetium has an atomic number of 43. Write the nuclear equation for the beta particle emission of technetium-99. What is the daughter isotope?
13. Energies of gamma rays are typically expressed in units of megaelectron volts (MeV), where  $1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$ . Using the data provided in the text, calculate the energy in megaelectron volts of the gamma ray emitted when radon-222 decays.
14. The gamma ray emitted when oxygen-19 gives off a beta particle is 0.197 MeV. What is its energy in joules? (See Exercise 13 for the definition of a megaelectron volt.)
15. Which penetrates matter more deeply—alpha particles or beta particles? Suggest ways to protect yourself against both particles.
16. Which penetrates matter more deeply—alpha particles or gamma rays? Suggest ways to protect yourself against both emissions.
17. Define *nuclear fission*.
18. What general characteristic is typically necessary for a nucleus to undergo spontaneous fission?

### Answers

1. Radioactivity is the spontaneous emission of particles and electromagnetic radiation from nuclei of unstable atoms.
- 2.
3.
  - a. 5 protons; 6 neutrons
  - b. 13 protons; 14 neutrons
  - c. 26 protons; 30 neutrons
  - d. 86 protons; 138 neutrons
- 4.
5. An alpha particle is a collection of two protons and two neutrons and is equivalent to a helium nucleus.
- 6.
7. Gamma rays are high-energy electromagnetic radiation given off in radioactive decay.
- 8.
9.  $^{244}_{94}\text{Pu} \rightarrow ^{240}_{92}\text{U} + ^4_2\text{He}$   
daughter isotope:  $^{240}_{92}\text{U}$

- 10.
11.  ${}_{50}^{121}\text{Sn} \rightarrow {}_{51}^{121}\text{Sb} + {}_{-1}^0\text{e}$   
daughter isotope:  ${}^{121}\text{Sb}$
- 12.
13. 0.51 MeV
- 14.
15. Beta particles penetrate more. A thick wall of inert matter is sufficient to block both particles.
- 16.
17. Nuclear fission is the breaking down of large nuclei into smaller nuclei, usually with the release of excess neutrons.
- 18.

#### 14.3: Half-Life

1. Do all isotopes have a half-life? Explain your answer.
2. Which is more radioactive—an isotope with a long half-life or an isotope with a short half-life?
3. How long does it take for 1.00 g of palladium-103 to decay to 0.125 g if its half-life is 17.0 d?
4. How long does it take for 2.00 g of niobium-94 to decay to 0.0625 g if its half-life is 20,000 y?
5. It took 75 y for 10.0 g of a radioactive isotope to decay to 1.25 g. What is the half-life of this isotope?
6. It took 49.2 s for 3.000 g of a radioactive isotope to decay to 0.1875 g. What is the half-life of this isotope?
7. The half-life of americium-241 is 432 y. If 0.0002 g of americium-241 is present in a smoke detector at the date of manufacture, what mass of americium-241 is present after 100.0 y? After 1,000.0 y?
8. If the half-life of tritium (hydrogen-3) is 12.3 y, how much of a 0.00444 g sample of tritium is present after 5.0 y? After 250.0 y?
9. Explain why the amount left after 1,000.0 y in Exercise 7 is not one-tenth of the amount present after 100.0 y, despite the fact that the amount of time elapsed is 10 times as long.
10. Explain why the amount left after 250.0 y in Exercise 8 is not one-fiftieth of the amount present after 5.0 y, despite the fact that the amount of time elapsed is 50 times as long.
11. An artifact containing carbon-14 contains  $8.4 \times 10^{-9}$  g of carbon-14 in it. If the age of the artifact is 10,670 y, how much carbon-14 did it have originally? The half-life of carbon-14 is 5,730 y.
12. Carbon-11 is a radioactive isotope used in positron emission tomography (PET) scans for medical diagnosis. Positron emission is another, though rare, type of radioactivity. The half-life of carbon-11 is 20.3 min. If  $4.23 \times 10^{-6}$  g of carbon-11 is left in the body after 4.00 h, what mass of carbon-11 was present initially?

#### Answers

1. Only radioactive isotopes have a half-life.
- 2.
3. 51.0 d
- 4.
5. 25 y
- 6.
7. 0.000170 g; 0.0000402 g
- 8.
9. Radioactive decay is an exponential process, not a linear process.
- 10.
11.  $3.1 \times 10^{-8}$  g
- 12.

#### 14.4: Applications of Nuclear Chemistry

1. Define *tracer* and give an example of how tracers work.
2. Name two isotopes that have been used as tracers.
3. Explain how radioactive dating works.
4. Name two isotopes that have been used in radioactive dating.

5. The current disintegration rate for carbon-14 is 14.0 Bq. A sample of burnt wood discovered in an archeological excavation is found to have a carbon-14 disintegration rate of 3.5 Bq. If the half-life of carbon-14 is 5,730 y, approximately how old is the wood sample?
6. A small asteroid crashes to Earth. After chemical analysis, it is found to contain 1 g of technetium-99 to every 3 g of ruthenium-99, its daughter isotope. If the half-life of technetium-99 is 210,000 y, approximately how old is the asteroid?
7. What is a positive aspect of the irradiation of food?
8. What is a negative aspect of the irradiation of food?
9. Describe how iodine-131 is used to both diagnose and treat thyroid problems.
10. List at least five organs that can be imaged using radioactive isotopes.
11. Which radioactive emissions can be used therapeutically?
12. Which isotope is used in therapeutics primarily for its gamma ray emissions?

### Answers

1. A tracer is a radioactive isotope that can be detected far from its original source to trace the path of certain chemicals. Hydrogen-3 can be used to trace the path of water underground.
- 2.
3. If the initial amount of a radioactive isotope is known, then by measuring the amount of the isotope remaining, a person can calculate how old that object is since it took up the isotope.
- 4.
5. 11,500 y
- 6.
7. increased shelf life (answers will vary)
- 8.
9. The thyroid gland absorbs most of the iodine, allowing it to be imaged for diagnostic purposes or preferentially irradiated for treatment purposes.
- 10.
11. gamma rays

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