Chemistry 2e
21: Nuclear Chemistry
21.1: Nuclear Structure and Stability

1. Write the following isotopes in hyphenated form (e.g., “carbon-14”)

(a) ${}^{24}_{11}\text{Na}$

(b) ${}^{29}_{13}\text{Al}$

(c) ${}^{73}_{36}\text{Kr}$

(d) ${}^{194}_{77}\text{Ir}$

Solution

(a) sodium-24; (b) aluminum-29; (c) krypton-73; (d) iridium-194

3. For the following isotopes that have missing information, fill in the missing information to complete the notation

(a) ${}^{34}_{14}\text{X}$

(b) ${}^{36}_{\text{X}}\text{P}$

(c) ${}^{57}_{\text{X}}\text{Mn}$

(d) ${}^{121}_{56}\text{X}$

Solution

(a) ${}^{34}_{14}\text{Si}$; (b) ${}^{36}_{15}\text{P}$; (c) ${}^{57}_{25}\text{Mn}$; (d) ${}^{121}_{56}\text{Ba}$

5. Write the nuclide notation, including charge if applicable, for atoms with the following characteristics:

(a) 25 protons, 20 neutrons, 24 electrons
(b) 45 protons, 24 neutrons, 43 electrons
(c) 53 protons, 89 neutrons, 54 electrons
(d) 97 protons, 146 neutrons, 97 electrons

Solution

(a) ${}^{45}_{25}\text{Mn}^{+1}$; (b) ${}^{69}_{45}\text{Rh}^{+2}$; (c) ${}^{142}_{53}\text{I}^{-1}$; (d) ${}^{243}_{97}\text{Bk}$

7. What are the two principal differences between nuclear reactions and ordinary chemical changes?

Solution

Nuclear reactions usually change one type of nucleus into another; chemical changes rearrange atoms. Nuclear reactions involve much larger energies than chemical reactions and have measureable mass changes.

9. Which of the following nuclei lie within the band of stability shown in Figure 21.2?

(a) chlorine-37
(b) calcium-40
(c) ${}^{204}\text{Bi}$
(d) ${}^{56}\text{Fe}$
(e) ${}^{206}\text{Pb}$
(f) ${}^{211}\text{Pb}$
(g) ${}^{222}\text{Rn}$
(h) carbon-14

Solution

(a), (b), (c), (d), and (e)

Chemistry 2e
21: Nuclear Chemistry
21.2: Nuclear Equations

11. Write a brief description or definition of each of the following:
(a) nucleon
(b) α particle
(c) β particle
(d) positron
(e) γ ray
(f) nuclide
(g) mass number
(h) atomic number

Solution

(a) A nucleon is any particle contained in the nucleus of the atom, so it can refer to protons and neutrons. (b) An α particle is one product of natural radioactivity and is the nucleus of a helium atom. (c) A β particle is a product of natural radioactivity and is a high-speed electron. (d) A positron is a particle with the same mass as an electron but with a positive charge. (e) Gamma rays compose electromagnetic radiation of high energy and short wavelength. (f) Nuclide is a term used when referring to a single type of nucleus. (g) The mass number is the sum of the number of protons and the number of neutrons in an element. (h) The atomic number is the number of protons in the nucleus of an element.

13. Complete each of the following equations by adding the missing species:

(a) ${}^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \longrightarrow ? + {}^{1}_{0}\text{n}$

(b) ${}^{239}_{94}\text{Pu} + ? \longrightarrow {}^{242}_{96}\text{Cm} + {}^{1}_{0}\text{n}$

(c) ${}^{235}_{92}\text{U} \longrightarrow ? + {}^{135}_{55}\text{Cs} + 4{}^{1}_{0}\text{n}$

(d) ${}^{235}_{92}\text{U} \longrightarrow ? + {}^{135}_{55}\text{Cs} + 4{}^{1}_{0}\text{n}$

Solution

(a) ${}^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \longrightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$; (b) ${}^{239}_{94}\text{Pu} + {}^{4}_{2}\text{He} \longrightarrow {}^{242}_{96}\text{Cm} + {}^{1}_{0}\text{n}$; (c) ${}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \longrightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$; (d) ${}^{235}_{92}\text{U} \longrightarrow {}^{96}_{37}\text{Rb} + {}^{135}_{55}\text{Cs} + 4{}^{1}_{0}\text{n}$

15. Write a balanced equation for each of the following nuclear reactions:
(a) the production of ${}^{17}\text{O}$ from ${}^{14}\text{N}$ by α particle bombardment
(b) the production of ${}^{14}\text{C}$ from ${}^{14}\text{N}$ by neutron bombardment
(c) the production of ${}^{233}\text{Th}$ from ${}^{232}\text{Th}$ by neutron bombardment
(d) the production of ${}^{239}\text{U}$ from ${}^{238}\text{U}$ by ${}^{2}_{1}\text{H}$ bombardment

Solution

(a) ${}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \longrightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$; (b) ${}^{14}_{7}\text{C} + {}^{1}_{0}\text{n} \longrightarrow {}^{14}_{6}\text{C} + {}^{1}_{1}\text{H}$; (c) ${}^{232}_{90}\text{Th} + {}^{1}_{0}\text{n} \longrightarrow {}^{233}_{90}\text{Th}$; (d) ${}^{238}_{92}\text{U} + {}^{2}_{1}\text{H} \longrightarrow {}^{239}_{92}\text{U} + {}^{1}_{1}\text{H}$

17. The mass of the atom ${}^{19}_{9}\text{F}$ is 18.99840 amu.
(a) Calculate its binding energy per atom in millions of electron volts.
(b) Calculate its binding energy per nucleon.

Solution

(a) Determine the mass defect of the nuclide, which is the difference between the mass of 9 protons, 10 neutrons, and 9 electrons, and the observed mass of a ${}^{19}_{9}\text{F}$ atom:

mass defect = [(9 × 1.0073 amu) + (10 × 1.0087 amu) + (9 × 0.00055 amu)] – 18.99840 amu = 19.15765 amu – 18.99840 amu = 0.15925 amu;

$$E = mc^2 = 0.15925\text{ amu} \times \frac{1.6605 \times 10^{-27}\text{ kg}}{1\text{ amu}} \times \left(2.998 \times 10^{8}\ \frac{m}{s}\right)^2$$

$= 2.377 \times 10^{-11}$ kg m/s^2
$= 2.377 \times 10^{-11}$ J

$$2.337 \times 10^{-11}\text{ J} \times \frac{1\text{ MeV}}{1.602 \times 10^{-13}\text{ J}} = 148.8\text{ MeV per atom};$$

(b) Binding energy per nucleon = $\frac{148.4\text{ MeV}}{19}$ = 7.808 MeV/nucleon

Chemistry 2e
21: Nuclear Chemistry
21.3: Radioactive Decay

19. What are the types of radiation emitted by the nuclei of radioactive elements?

Solution

α (helium nuclei), β (electrons), β^+ (positrons), and η (neutrons) may be emitted from a radioactive element, all of which are particles; γ rays also may be emitted.

21. What is the change in the nucleus that results from the following decay scenarios?
(a) emission of a β particle
(b) emission of a β^+ particle
(c) capture of an electron

Solution

(a) conversion of a neutron to a proton: ${}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{0}_{+1}\text{e}$; (b) conversion of a proton to a neutron; the positron has the same mass as an electron and the same magnitude of positive charge as the electron has negative charge; when the n:p ratio of a nucleus is too low, a proton is converted into a neutron with the emission of a positron: ${}^{1}_{1}\text{p} \longrightarrow {}^{1}_{0}\text{n} + {}^{0}_{+1}\text{e}$; (c) In a proton-rich nucleus, an inner atomic electron can be absorbed. In simplifies form, this changes a proton into a neutron: ${}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} \longrightarrow {}^{1}_{0}\text{n}$

23. Why is electron capture accompanied by the emission of an X-ray?

Solution

The electron pulled into the nucleus was most likely found in the 1*s* orbital. As an electron falls from a higher energy level to replace it, the difference in the energy of the replacement electron in its two energy levels is given off as an X-ray.

25. Which of the following nuclei is most likely to decay by positron emission? Explain your choice.
(a) chromium-53
(b) manganese-51
(c) iron-59

Solution

Manganese-51 is most likely to decay by positron emission. The n:p ratio for Cr-53 is $\frac{29}{24}$ = 1.21; for Mn-51, it is $\frac{26}{25}$ = 1.04; for Fe-59, it is $\frac{33}{26}$ = 1.27. Positron decay occurs when the n:p ratio is low. Mn-51 has the lowest n:p ration and therefore is most likely to decay by positron emission. Besides, ${}^{53}_{24}\text{Cr}$ is a stable isotope, and ${}^{59}_{26}\text{Fe}$ decays by beta emission.

27. The following nuclei do not lie in the band of stability. How would they be expected to decay?
(a) ${}^{28}_{15}\text{P}$
(b) ${}^{235}_{92}\text{U}$
(c) ${}^{37}_{20}\text{Ca}$
(d) ${}^{9}_{3}\text{Li}$
(e) ${}^{245}_{96}\text{Cm}$

Solution

(a) too many neutrons, β decay; (b) atomic number greater than 82, α decay; (c) too few neutrons, positron emission; (d) too many neutrons, β decay; (e) atomic number greater than 83, α decay

29. Write a nuclear reaction for each step in the formation of ${}^{218}_{84}\text{Po}$ from ${}^{238}_{98}\text{U}$, which proceeds by a series of decay reactions involving the step-wise emission of α, β, β, α, α, α particles, in that order.

Solution

$${}^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}\,;\ {}^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}\,;\ {}^{234}_{91}\text{Pa} \longrightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\text{e}\,;$$

$${}^{234}_{92}\text{U} \longrightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}\,;\ {}^{230}_{90}\text{Th} \longrightarrow {}^{226}_{88}\text{Ra} + {}^{4}_{2}\text{He}\,;\ {}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}\,;$$

$${}^{222}_{86}\text{Rn} \longrightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

31. Define the term half-life and illustrate it with an example.

Solution

Half-life is the time required for half the atoms in a sample to decay. Example (answers may vary): For C-14, the half-life is 5770 years. A 10-g sample of C-14 would contain 5 g of C-14 after 5770 years; a 0.20-g sample of C-14would contain 0.10 g after 5770 years.

33. ${}^{239}\text{Pu}$ is a nuclear waste byproduct with a half-life of 24,000 y. What fraction of the ${}^{239}\text{Pu}$ present today will be present in 1000 y?

Solution

1000 years is 0.04 half-lives. The fraction that remains after 0.04 half-lives is $\left(\frac{1}{2}\right)^{0.04} = 0.973$ or 97.3%

35. If 1.000 g of ${}^{226}_{88}\text{Ra}$ produces 0.0001 mL of the gas ${}^{222}_{86}\text{Rn}$ at STP (standard temperature and pressure) in 24 h, what is the half-life of ${}^{226}\text{Ra}$ in years?

Solution

$PV = nRT$

$$n_{\text{Rn}} = \frac{PV}{RT} = \frac{(1\ \text{atm})(0.0001\ \text{mL} \times 1\ \text{L}/10^3\ \text{mL})}{(0.08206\ \text{L atm mol}^{-1}\ \text{K}^{-1})(273.15\ \text{K})} = 4.4614 \times 10^{-9}\text{mol}$$

n_{Rn} produced = n_{Rn} decayed

$$\text{mass Ra lost} = 4.4614 \times 10^{-9}\ \text{mol} \times \frac{226\ \text{g}}{\text{mol}} = 1.00827 \times 10^{-6}\ \text{g}$$

$$\text{mass Ra remaining after 24 h} = 1 - (1.00827 \times 10^{-6}\ \text{g}) = 9.9999899 \times 10^{-1}\ \text{g}$$

$$\ln\frac{c_0}{c} = \lambda t = \ln\frac{1.000}{9.9999899 \times 10^{-1}} = \lambda(24\ \text{h}) = 4.3785 \times 10^{-7}$$

$$\lambda = 4.2015 \times 10^{-8}\ \text{h}^{-1}$$

$$t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{4.2015 \times 10^{-8}} = 1.6494 \times 10^{7}\ \text{h}$$

$$= 1.6494 \times 10^{7}\ \text{h} \times \frac{1\ \text{d}}{24\ \text{h}} \times \frac{1\ \text{y}}{365\ \text{d}} = 1.883 \times 10^{3}\ \text{y or } 2 \times 10^{3}\ \text{y}$$

37. Technetium-99 is often used for assessing heart, liver, and lung damage because certain technetium compounds are absorbed by damaged tissues. It has a half-life of 6.0 h. Calculate the rate constant for the decay of ${}^{99}_{43}\text{Tc}$.

Solution

(Recall that radioactive decay is a first-order process.)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}} = \frac{0.693}{6.0\ \text{h}} = 0.12\ \text{h}^{-1}$$

39. A sample of rock was found to contain 8.23 mg of rubidium-87 and 0.47 mg of strontium-87.
(a) Calculate the age of the rock if the half-life of the decay of rubidium by β emission is 4.7×10^{10} y.
(b) If some ${}^{87}_{38}\text{Sr}$ was initially present in the rock, would the rock be younger, older, or the same age as the age calculated in (a)? Explain your answer.

Solution

(a) ${}^{87}_{37}\text{Rb} \longrightarrow {}^{87}_{38}\text{Sr} + {}^{0}_{-1}\text{e}$

${}^{87}_{38}\text{Sr}$ is a stable isotope and does not decay further. Calculate the value of the decay rate constant for ${}^{87}_{37}\text{Rb}$, remembering that all radioactive decay is first order:

$$\lambda = \frac{0.693}{4.7 \times 10^{10}\ \text{y}} = 1.47 \times 10^{-11}\ \text{y}^{-1}$$

Calculate the number of moles of ${}^{87}_{37}\text{Rb}$ and ${}^{87}_{38}\text{Sr}$ found in the sample at time *t*:

$$8.23\ \text{mg} \times \frac{1\ \text{g}}{1000\ \text{mg}} \times \frac{1\ \text{mol}}{87.0\ \text{g}} = 9.46 \times 10^{-5}\ \text{mol of}\ {}^{87}_{37}\text{Rb}$$

$$0.47\ \text{mg} \times \frac{1\ \text{g}}{1000\ \text{mg}} \times \frac{1\ \text{mol}}{87.0\ \text{g}} = 5.40 \times 10^{-6}\ \text{mol of}\ {}^{87}_{38}\text{Sr}$$

Each mol of ${}^{87}_{37}\text{Rb}$ that disappeared (by radioactive decay of the ${}^{87}_{37}\text{Rb}$ initially present in the rock) produced 1 mol of ${}^{87}_{38}\text{Sr}$. Hence the number of moles of ${}^{87}_{38}\text{Rb}$ that disappeared by radioactive decay equals the number of moles of ${}^{87}_{38}\text{Sr}$ that were produced. This amount consists of the 5.40×10^{-6}mol of ${}^{87}_{38}\text{Sr}$ found in the rock at time *t* if all the ${}^{87}_{38}\text{Sr}$ present at time *t* resulted from radioactive decay of ${}^{87}_{37}\text{Rb}$ and no strontium-87 was present initially in the rock. Using this assumption, we can calculate the total number of moles of rubidium-87 initially present in the rock:

Total number of moles of ${}^{87}_{37}\text{Rb}$ initially present in the rock at time t_0 = number of moles of ${}^{87}_{37}\text{Rb}$ at time *t* + number of moles of ${}^{87}_{37}\text{Rb}$ that decayed during the time interval $t - t_0$ = number of moles of ${}^{87}_{37}\text{Rb}$ measured at time *t* + number of moles of ${}^{87}_{38}\text{Sr}$ measured at time $t = 9.46 \times 10^{-5}\text{mol} + 5.40 \times 10^{-6}\text{mol} = 1.00 \times 10^{-4}\text{mol}$

The number of moles can be substituted for concentrations in the expression:

$$\ln\frac{c_0}{c_t} = \lambda t$$

Thus:

$$\ln\frac{1.00 \times 10^{-4}\ \text{mol}}{9.46 \times 10^{-5}\ \text{mol}} = (1.47 \times 10^{-11})t$$

$$t = \left(\ln\frac{1.00 \times 10^{-4}}{9.46 \times 10^{-5}}\right)\left(\frac{1}{1.47 \times 10^{-11}\ \text{y}^{-1}}\right)$$

= 3.8 × 109 y = 3.8 billion years = age of the rock sample;
(b) The rock would be younger than the age calculated in part (a). If Sr was originally in the rock, the amount produced by radioactive decay would equal the present amount minus the initial amount. As this amount would be smaller than the amount used to calculate the age of the rock and the age is proportional to the amount of Sr, the rock would be younger.

41. Plutonium was detected in trace amounts in natural uranium deposits by Glenn Seaborg and his associates in 1941. They proposed that the source of this ^{239}Pu was the capture of neutrons by ^{238}U nuclei. Why is this plutonium not likely to have been trapped at the time the solar system formed 4.7×10^{9} years ago?

Solution

$^{239}_{94}\text{Pu}$ has a half-life of 2.411×10^{4} y. Calculate the value of λ and then determine the amount of plutonium-239 remaining after 4.7×10^{9} y:

$$\lambda t = \lambda(2.411 \times 10^{4}\ \text{y}) = \ln\left(\frac{1.0000}{0.5000}\right) = 0.6931$$

$$\lambda = \frac{0.6931}{2.411} \times 10^{4}\ \text{y} = 2.875 \times 10^{-5}\ \text{y}^{-1}$$

Then:

$$\ln\frac{c_0}{c} = \lambda t$$

$$\ln\left(\frac{1.000}{c}\right) = 2.875 \times 10^{-5}\ \text{y}^{-1} \times 4.7 \times 10^{9}\ \text{y}$$

$$\ln c = -1.351 \times 10^{5}$$

$$c = 0$$

This calculation shows that no Pu-239 could remain since the formation of the earth. Consequently, the plutonium now present could not have been formed with the uranium.

43. A $^{8}_{5}\text{B}$ atom (mass = 8.0246 amu) decays into a $^{8}_{4}\text{B}$ atom (mass = 8.0053 amu) by loss of a β^{+} particle (mass = 0.00055 amu) or by electron capture. How much energy (in millions of electron volts) is produced by this reaction?

Solution

Find the mass difference of the starting mass and the total masses of the final products. Then use the conversion for mass to energy to find the energy released:

$$8.0246 - 8.0053 - 0.00055 = 0.01875\ \text{amu}$$

$$0.01875\ \text{amu} \times 1.6605 \times 10^{-27}\ \text{kg/amu} = 3.113 \times 10^{-29}\ \text{kg}$$

$$E = mc^{2} = (3.113 \times 10^{-29}\ \text{kg})(2.9979 \times 10^{8}\ \text{m/s})^{2}$$

$$= 2.798 \times 10^{-12}\ \text{kg m}^{2}/\text{s}^{2} = 2.798 \times 10^{-12}\ \text{J/nucleus}$$

$$2.798 \times 10^{-12}\ \text{J/nucleus} \times \frac{1\ \text{MeV}}{1.602177 \times 10^{-13}\ \text{J}} = 17.5\ \text{MeV}$$

45. Write a balanced equation for each of the following nuclear reactions:
(a) bismuth-212 decays into polonium-212
(b) beryllium-8 and a positron are produced by the decay of an unstable nucleus
(c) neptunium-239 forms from the reaction of uranium-238 with a neutron and then spontaneously converts into plutonium-239
(d) strontium-90 decays into yttrium-90

Solution

(a) ${}^{212}_{83}\text{Bi} \longrightarrow {}^{212}_{84}\text{Po} + {}^{0}_{-1}\text{e}$; (b) ${}^{8}_{5}\text{B} \longrightarrow {}^{8}_{4}\text{Be} + {}^{0}_{-1}\text{e}$; (c) ${}^{238}_{92}\text{U} + {}^{1}_{0}\text{n} \longrightarrow {}^{239}_{93}\text{Np} + {}^{0}_{-1}\text{Np}$, ${}^{239}_{93}\text{Np} \longrightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e}$; (d) ${}^{90}_{38}\text{Sr} \longrightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\text{e}$

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21: Nuclear Chemistry
21.4: Transmutation and Nuclear Energy

47. Write the balanced nuclear equation for the production of the following transuranium elements:
(a) berkelium-244, made by the reaction of Am-241 and He-4
(b) fermium-254, made by the reaction of Pu-239 with a large number of neutrons
(c) lawrencium-257, made by the reaction of Cf-250 and B-11
(d) dubnium-260, made by the reaction of Cf-249 and N-15

Solution

(a) ${}^{241}_{95}\text{Am} + {}^{4}_{2}\text{He} \longrightarrow {}^{244}_{97}\text{Bk} + {}^{1}_{0}\text{n}$; (b) ${}^{239}_{94}\text{Pu} + 15\,{}^{1}_{0}\text{n} \longrightarrow {}^{254}_{100}\text{Fm} + 6\,{}^{0}_{-1}\text{e}$;
(c) ${}^{250}_{98}\text{Cf} + {}^{11}_{5}\text{B} \longrightarrow {}^{257}_{103}\text{Lr} + 4\,{}^{1}_{0}\text{n}$; (d) ${}^{249}_{98}\text{Cf} + {}^{15}_{7}\text{N} \longrightarrow {}^{260}_{105}\text{Db} + 4\,{}^{1}_{0}\text{n}$

49. Both fusion and fission are nuclear reactions. Why is a very high temperature required for fusion, but not for fission?

Solution

Two nuclei must collide for fusion to occur. High temperatures are required to give the nuclei enough kinetic energy to overcome the very strong repulsion resulting from their positive charges.

51. Describe the components of a nuclear reactor.

Solution

A nuclear reactor consists of the following:
1. A nuclear fuel. A fissionable isotope must be present in large enough quantities to sustain a controlled chain reaction. The radioactive isotope is contained in tubes called fuel rods.
2. A moderator. A moderator slows neutrons produced by nuclear reactions so that they can be absorbed by the fuel and cause additional nuclear reactions.
3. A coolant. The coolant carries heat from the fission reaction to an external boiler and turbine where it is transformed into electricity.
4. A control system. The control system consists of control rods placed between fuel rods to absorb neutrons and is used to adjust the number of neutrons and keep the rate of the chain reaction at a safe level.
5. A shield and containment system. The function of this component is to protect workers from radiation produced by the nuclear reactions and to withstand the high pressures resulting from high-temperature reactions.

53. Describe how the potential energy of uranium is converted into electrical energy in a nuclear power plant.

Solution

fission of uranium generates heat, which is carried to an external steam generator (boiler). The resulting steam turns a turbine that powers an electrical generator.

Chemistry 2e
21: Nuclear Chemistry
21.5: Uses of Radioisotopes

55. How can a radioactive nuclide be used to show that the equilibrium:

$$\mathrm{AgCl}(s) \rightleftharpoons \mathrm{Ag}^{+}(aq) + \mathrm{Cl}^{-}(aq)$$

is a dynamic equilibrium?

Solution

Introduction of either radioactive Ag^{+} or radioactive Cl^{-} into the solution containing the stated reaction, with subsequent time given for equilibration, will produce a radioactive precipitate that was originally devoid of radiation.

57. Iodine that enters the body is stored in the thyroid gland from which it is released to control growth and metabolism. The thyroid can be imaged if iodine-131 is injected into the body. In larger doses, I-133 is also used as a means of treating cancer of the thyroid. I-131 has a half-life of 8.70 days and decays by β^{-} emission.

(a) Write an equation for the decay.

(b) How long will it take for 95.0% of a dose of I-131 to decay?

Solution

(a) ${}^{133}_{53}\mathrm{I} \longrightarrow {}^{133}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e}$;

(b) First, find the value of λ:

$$\lambda = \frac{0.6931}{8.70\text{ day}} = 0.07967\text{ day}^{-1}$$

$$\frac{\ln c_0}{c} = \lambda t;\ \ln\left(\frac{1.000}{0.050}\right) = 0.07967\text{ day}^{-1}$$

$$t = \frac{2.996}{0.07967\text{ day}^{-1}} = 37.6\text{ days}$$

Chemistry 2e
21: Nuclear Chemistry
21.6: Biological Effects of Radiation

59. Based on what is known about Radon-222's primary decay method, why is inhalation so dangerous?

Solution

Alpha particles can be stopped by very thin shielding but have much stronger ionizing potential than beta particles, X-rays, and γ-rays. When inhaled, there is no protective skin covering the cells of the lungs, making it possible to damage the DNA in those cells and cause cancer.

61. A scientist is studying a 2.234 g sample of thorium-229 ($t_{1/2}$ = 7340 y) in a laboratory.
(a) What is its activity in Bq?
(b) What is its activity in Ci?

Solution

$$\text{Activity} = \lambda N = \left(\frac{\ln\ 2}{t_{1/2}}\right)N = \left(\frac{\ln\ 2}{7340\ \text{y}}\right)2.234\ \text{g} = 9.162 \times 10^{-5}\ \frac{\text{g}}{\text{y}}$$

(a) Converted to Bq:

$$9.162 \times 10^{-5}\ \frac{\text{g}}{\text{y}} \times \frac{1\ \text{y}}{365\ \text{d}} \times \frac{1\ \text{d}}{24\ \text{h}} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1\ \text{mol}}{229\ \text{g}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} \times \frac{1\ \text{decay}}{1\ \text{atom}}$$

$$= 7.64 \times 10^{9}\ \frac{\text{decays}}{\text{s}} = 7.64 \times 10^{9}\ \text{Bq}$$

(b) Converted to Ci:

$$7.64 \times 10^{9}\ \frac{\text{decays}}{\text{s}} \times \left(\frac{1\ \text{Ci}}{3.7 \times 10^{11}\ \frac{\text{decays}}{\text{s}}}\right) = 2.06 \times 10^{-2}\ \text{Ci}$$