2

Atoms and Radioactivity

Chapter 2 is an introduction to the atom. Introduction to basic atomic structure refocuses the student's attention on the periodic table through the introduction of atomic numbers and atomic mass. From this foundation, the chapter builds on its discussion of isotopes to lead into radioisotopes and the elementary concepts of nuclear chemistry. More complex concepts of nuclear chemistry are simplified with new problem-solving features on nuclear decay equations and half-life. Dosing is re-emphasized in a discussion of medical radioisotopes.

Chapter Outline

2.1 Atoms and Their Components

2.2 Atomic Number and Mass Number

Discovering the Concepts: Isotopes

2.3 Isotopes and Atomic Mass

2.4 Radioactivity and Radioisotopes

Integrating Chemistry: Biological Effects of Radiation

Discovering the Concepts: Radioactivity

2.5 Nuclear Equations and Radioactive Decay

Solving a Problem: Writing a Nuclear Decay Equation for Beta Decay

2.6 Radiation Units and Half-Lives

Solving a Problem: Determining Half-Life

2.7 Medical Applications for Radioisotopes

Integrating Chemistry: Radioisotopes and Cancer Treatment

Learning Outcomes

Section 2.1: Atoms and Their Components
• Name the kind of subatomic particles that make up an atom.
• Locate the subatomic particles in an atom.
• Predict the mass of an atom from the number of subatomic particles.

Section 2.2: Atomic Number and Mass Number
• Define atomic number.
• Determine the mass number for a given atom.

Section 2.3: Isotopes and Atomic Mass
• Define isotope.
• Distinguish between mass number and atomic mass.

Section 2.4: Radioactivity and Radioisotopes
• Define radioactivity.
• Distinguish the forms of ionizing radiation.
• Differentiate the penetrating power of the forms of ionizing radiation.

Section 2.5: Nuclear Equations and Radioactive Decay
• Write a balanced nuclear decay equation for alpha, beta, gamma, and positron emissions.

Section 2.6; Radiation Units and Half-Lives
• Perform dosing calculations using radiation activity units.
• Determine the remaining dose of a radioactive isotope given the half-life.

Section 2.7: Medical Applications for Radioisotopes
• Contrast the use of radioisotopes for the diagnosis and treatment of disease.

Chapter 2

Answers to Problems

Practice Problems

2.1 Protons and neutrons are located in the nucleus (center) of an atom, and the electrons are found in a cloud outside of the nucleus called the electron cloud.

2.2 The mass of a proton is almost the same as the mass of the neutron.

2.3 The mass of an electron is about 2000 times smaller than that of a proton.

2.4 The mass unit amu (atomic mass unit) is used to describe the mass of protons and neutrons.

2.5 **a.** The number of protons is the atomic number.
b. The number of neutrons is the mass number minus the atomic number.
c. The number of electrons is the same as the number of protons in an atom.

2.6 **a.** The mass number indicates the total number of protons and neutrons in an atom.

b. The atomic number indicates the number of protons in an atom.

c. The mass number minus the atomic number indicates the number of neutrons in an atom.

2.7 **a.** oxygen, O **b.** magnesium, Mg
c. neon, Ne **d.** copper, Cu
e. silver, Ag

2.8 **a.** gold, Au **b.** potassium, K
c. lead, Pb **d.** arsenic, As
e. sodium, Na

2.9 14

2.10 33

2.11 **a.** 35 protons, 45 neutrons, 35 electrons
b. 11 protons, 12 neutrons, 11 electrons

2.12 **a.** 1 proton, 0 neutrons, 1 electron
b. 16 protons, 16 neutrons, 16 electrons

2.13 **a.** $^{4}_{2}He$ **b.** $^{35}_{17}Cl$ **c.** $^{32}_{16}S$ **d.** $^{133}_{55}Cs$

2.14 **a.** $^{7}_{3}Li$ **b.** $^{17}_{7}N$ **c.** $^{31}_{15}P$ **d.** $^{106}_{46}Pd$

2.15 **a.** 8 protons, 10 neutrons, 8 electrons
b. 20 protons, 20 neutrons, 20 electrons
c. 47 protons, 61 neutrons, 47 electrons
d. 82 protons, 125 neutrons, 82 electrons

2.16 **a.** 1 proton, 1 neutron, 1 electron

b. 13 protons, 14 neutrons, 13 electrons

c. 11 protons, 12 neutrons, 11 electrons

d. 9 protons, 10 neutrons, 9 electrons

2.17 The isotope carbon-12 contains exactly 6 protons and 6 neutrons. The atomic mass as seen on the periodic table is an average mass taking into consideration the abundance of all the carbon isotopes. Because about 1% of the carbon isotopes are carbon-13, the atomic mass is slightly higher than 12 amu.

2.18 The mass number is the total of the protons and neutrons in the nucleus of a specific atom. The atomic mass is the weighted average mass of all the atoms in a sample.

2.19 **a.** Magnesium-24 has 12 neutrons, magnesium-25 has 13 neutrons, magnesium-26 has 14 neutrons.

b. ${}^{24}_{12}\text{Mg}$, ${}^{25}_{12}\text{Mg}$, ${}^{26}_{12}\text{Mg}$

c. magnesium-24

2.20 **a.** Tin-118 has 68 neutrons, tin-119 has 69 neutrons, tin-120 has 70 neutrons, tin-124 has 74 neutrons.

b. ${}^{118}_{50}\text{Sn}$, ${}^{119}_{50}\text{Sn}$, ${}^{120}_{50}\text{Sn}$, ${}^{124}_{50}\text{Sn}$

2.21 An alpha particle is a helium nucleus. There are no electrons in an alpha particle.

2.22 A beta particle has a negative one charge, an alpha particle has a positive two charge, and a positron has a positive one charge.

2.23 gamma

2.24 Gamma rays are most similar because no subatomic particles are given off, just high-energy radiation. X-rays are generated by high-energy electron processes, they are not nuclear radiation.

2.25 **a.** ${}^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e}$

b. ${}^{212}_{84}\text{Po} \rightarrow {}^{208}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

c. ${}^{66}_{29}\text{Cu} \rightarrow {}^{66}_{30}\text{Zn} + {}^{0}_{-1}\text{e}$

d. ${}^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + {}^{0}_{1}\text{e}$

2.26 **a.** ${}^{232}_{90}\text{Th} \rightarrow {}^{228}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

b. ${}^{92}_{38}\text{Sr} \rightarrow {}^{92}_{39}\text{Y} + {}^{0}_{-1}\text{e}$

c. ${}^{13}_{7}\text{N} \rightarrow {}^{13}_{6}\text{C} + {}^{0}_{1}\text{e}$

d. ${}^{251}_{98}\text{Cf} \rightarrow {}^{247}_{96}\text{Cm} + {}^{4}_{2}\text{He}$

2.27 The half-lives are shorter, and they are prepared in the lab.

2.28 The half-life is the amount of time it takes for one-half of the atoms in a radioisotope to decay (give off radiation).

2.29 $50\ \cancel{\text{mCi}}\ \text{x}\ \dfrac{20\,\text{mL}}{250\ \cancel{\text{mCi}}} = 4\,\text{mL}$

2.30 $120\ \cancel{\text{mCi}}\ \text{x}\ \dfrac{\text{patient}}{15\ \cancel{\text{mCi}}} = 8\,\text{patients}$

2.31 $400\ \mu\text{Ci} \xrightarrow[\text{1 half-life}]{\text{8 days}} 200\ \mu\text{Ci} \xrightarrow[\text{2 half-lives}]{\text{16 days}} 100\ \mu\text{Ci} \xrightarrow[\text{3 half-lives}]{\text{24 days}} 50\ \mu\text{Ci} \xrightarrow[\text{4 half-lives}]{\text{32 days}} 25.0\ \mu\text{Ci}$

2.32 In this problem, the final answer will have two significant figures. In order to eliminate rounding errors, it is important to obtain the final answer before rounding.

$$25\ \text{mCi} \xrightarrow[\text{1 half-life}]{\text{6 hours}} 12.5\ \text{mCi} \xrightarrow[\text{2 half-lives}]{\text{12 hours}} 6.25\ \text{mCi} \xrightarrow[\text{3 half-lives}]{\text{18 hours}} 3.125\ \text{mCi} \xrightarrow[\text{4 half-lives}]{\text{24 hours}} 1.5625\ \text{mCi} \xrightarrow[\text{5 half-lives}]{\text{30 hours}}$$

$$0.78125\ \text{mCi} \xrightarrow[\text{6 half-lives}]{\text{36 hours}} 0.390625\ \text{mCi} \xrightarrow[\text{7 half-lives}]{\text{42 hours}} 0.195\ \text{mCi} \xrightarrow[\text{8 half-lives}]{\text{48 hours}} 0.098\ \text{mCi}$$

2.33 Ca-47 will concentrate in bone.

2.34 A diagnostic tracer is a radioisotope used in minimal amounts for detection of a diseased state. It should be administered in small amounts, concentrate in the area of interest, and have a short half-life.

2.35 $40\ \mu\text{Ci} \xrightarrow[\text{1half-life}]{} 20\ \mu\text{Ci} \xrightarrow[\text{2half-lives}]{} 10\ \mu\text{Ci} \xrightarrow[\text{3 half-lives}]{} 5.0\ \mu\text{Ci}$

After 3 half-lives (84 days), the patient will have less than one-tenth the original dose.

2.36 $300\ \mu\text{Ci} \xrightarrow[\text{1 half-life}]{} 150\ \mu\text{Ci} \xrightarrow[\text{2 half-lives}]{} 75\ \mu\text{Ci} \xrightarrow[\text{3 half-lives}]{} 37.5\ \mu\text{Ci}$

about 40 μCi after 40 hours

Additional Problems

2.37 **a.** neutron **b.** protons **c.** isotopes

2.38 **a.** protons; neutrons **b.** nucleus **c.** protons; electrons

2.39 **a.** 79 protons, 79 electrons

b. 30 protons, 30 electrons

c. 29 protons, 29 electrons

2.40 **a.** 17 protons and 17 electrons

b. 11 protons and 11 electrons

c. 16 protons and 16 electrons

2.41 **a.** 26 protons, 29 neutrons, 26 electrons

b. 7 protons, 8 neutrons, 7 electrons

c. 24 protons, 28 neutrons, 24 electrons

d. 56 protons, 81 neutrons, 56 electrons

2.42 **a.** 19 protons, 20 neutrons, 19 electrons

b. 8 protons, 8 neutrons, 8 electrons

c. 35 protons, 46 neutrons, 35 protons

d. 2 protons, 2 neutrons, 2 electrons

2.43

Symbol	**Number of Protons**	**Number of Neutrons**	**Number of Electrons**	**Mass Number**	**Name**
${}^{1}_{1}H$	**1**	**0**	**1**	**1**	**Hydrogen-1**
$\mathbf{{}^{24}_{12}Mg}$	12	12	12	**24**	**Magnesium-12**
${}^{9}_{4}Be$	**4**	5	**4**	**9**	**Beryllium-9**

2.44

Symbol	**Number of Protons**	**Number of Neutrons**	**Number of Electrons**	**Mass Number**	**Name**
${}^{14}_{6}C$	**6**	**8**	**6**	14	**Carbon-14**
$\mathbf{{}^{75}_{35}Br}$	35	40	35	**75**	**Bromine-75**

$^{50}_{27}Co$	**27**	**23**	27	**50**	**Cobalt-50**

2.45 **a.** alpha particle **b.** beta particle **c.** gamma radiation

2.46 **a.** alpha particle **b.** gamma radiation **c.** beta particle

2.47 **a.** $^{32}_{15}P$ **b.** $^{60}_{27}Co$ **c.** $^{51}_{24}Cr$

2.48 **a.** $^{238}_{92}U$ **b.** $^{143}_{54}Xe$ **c.** $^{131}_{53}I$

2.49 (answers in boldface)

Isotope Name	Symbolic Notation	Number of Protons	Number of Neutrons	Mass Number	Medical Use
Thallium-201	$^{201}_{81}Tl$	**81**	**120**	**201**	Tumor Imaging
Iodine-123	$^{123}_{53}I$	53	**70**	**123**	Thyroid Imaging
Xenon-133	$^{133}_{54}Xe$	54	**79**	133	Pulmonary Ventilation Imaging
Fluorine-18	$^{18}_{9}F$	**9**	**9**	**18**	Positron Emission Tomography (PET) Imaging

2.50 (answers in boldface)

Isotope Name	Symbolic Notation	Number of Protons	Number of Neutrons	Mass Number	Medical Use
Carbon-14	$^{14}_{6}C$	**6**	**8**	**14**	Used in breast tumor detection
Palladium-103	$^{103}_{46}Pd$	46	**57**	**103**	Prostate cancer treatment
Ytterbium-169	$^{169}_{70}Yb$	70	**99**	**169**	Gastrointestinal tract diagnoses
Xenon-127	$^{127}_{54}Xe$	**54**	**73**	**127**	Brain Imaging for mental disorders

2.51 **a.** $^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{1}e$

b. $^{46}_{23}V \rightarrow {}^{46}_{24}Cr + {}^{0}_{-1}e$

c. ${}^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}$

d. ${}^{8}_{4}\text{Be} \rightarrow {}^{4}_{2}\text{He} + {}^{4}_{2}\text{He}$

2.52 **a.** ${}^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}\text{e}$

b. ${}^{18}_{8}\text{O} + {}^{0}_{-1}\text{e} \rightarrow {}^{17}_{7}\text{N} + {}^{1}_{0}\text{n}$

c. ${}^{218}_{84}\text{Po} \rightarrow {}^{214}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

d. ${}^{60}_{27}\text{Co} \rightarrow {}^{60}_{27}\text{Co} + {}^{0}_{0}\gamma$

2.53 **a.** ${}^{66}_{29}\text{Cu} \rightarrow {}^{66}_{30}\text{Zn} + {}^{0}_{-1}\text{e}$

b. ${}^{192}_{78}\text{Pt} \rightarrow {}^{188}_{76}\text{Os} + {}^{4}_{2}\text{He}$

c. ${}^{126}_{50}\text{Sn} \rightarrow {}^{126}_{51}\text{Sb} + {}^{0}_{-1}\text{e}$

d. ${}^{72}_{31}\text{Ga} \rightarrow {}^{72}_{32}\text{Ge} + {}^{0}_{-1}\text{e}$

2.54 **a.** ${}^{225}_{90}\text{Th} \rightarrow {}^{221}_{88}\text{Ra} + {}^{4}_{2}\text{He}$

b. ${}^{210}_{83}\text{Bi} \rightarrow {}^{206}_{81}\text{Tl} + {}^{4}_{2}\text{He}$

c. ${}^{137}_{55}\text{Cs} \rightarrow {}^{137}_{56}\text{Ba} + {}^{0}_{-1}\text{e}$

d. ${}^{35}_{16}\text{S} \rightarrow {}^{35}_{17}\text{Cl} + {}^{0}_{-1}\text{e}$

2.55 ${}^{10}_{5}\text{B} + {}^{4}_{2}\text{He} \rightarrow {}^{12}_{7}\text{N} + 2\,{}^{1}_{0}\text{n}$

2.56 ${}^{52}_{26}\text{Fe} \rightarrow {}^{52}_{25}\text{Mn} + {}^{0}_{1}\text{e}$

2.57 1.3 mL

2.58 2.5 mL

2.59 12.5 mg

2.60 7.5 mg

2.61 13.2 hours

2.62 14.3 days

2.63 A cold spot indicates a diseased area of an organ; a hot spot indicates an area of the organ where the cells are dividing rapidly or a cancerous growth.

2.64 Both external beam radiation therapy and brachytherapy use radiation to destroy harmful tissues. External beam radiation therapy uses an external source of radiation. In brachytherapy, small capsules containing the radioisotopes are placed at the site of the tumor.

Challenge Problems

2.65 1.56%

2.66 11,500 years old

2.67 Because a person with a more active brain uses more glucose, more FDG will be present in the brain. The PET image would be brighter in more areas than for the normal person.