Pearson

Chapter Summary and Review

Key Learning Outcomes

CHAPTER OBJECTIVES	ASSESSMENT
Write Nuclear Equations for Alpha Decay (20.3)	• Example 20.1 For Practice 20.1 Exercises 31, 32, 33, 34, 35, 36
Write Nuclear Equations for Beta Decay, Positron Emission, and Electron Capture (20.3)	• Example 20.2 For Practice 20.2 For More Practice 20.2 Exercises 31, 32, 33, 34, 35, 36
Predict the Type of Radioactive Decay (20.4)	• Example 20.3 For Practice 20.3 Exercises 41, 42
Use Radioactive Decay Kinetics (20.6)	• Example 20.4 For Practice 20.4 Exercises 45, 46, 47, 48, 49, 50, 51, 52
Use Radiocarbon Dating (20.6)	• Example 20.5 For Practice 20.5 Exercises 53, 54
Use Uranium/Lead Dating (20.6)	• Example 20.6 For Practice 20.6 Exercises 55, 56
Determine the Mass Defect and Nuclear Binding Energy (20.8)	• Example 20.7 For Practice 20.7 Exercises 65, 66, 67, 68, 69, 70, 71, 72

Key Terms

Section 20.1

radioactivity
radioactive

Section 20.2

phosphorescence

Section 20.3

nuclide
alpha (α) decay

alpha (α) particle
nuclear equation
ionizing power
penetrating power
beta (β) decay
beta (β) particle
gamma (γ) ray emission
gamma (γ) ray
positron emission
positron
electron capture

Section 20.4

nucleons
strong force
magic numbers

Section 20.5

thermoluminescent dosimeter
Geiger-Müller counter
scintillation counter

Section 20.6

radiometric dating
radiocarbon dating

Section 20.7

nuclear fission
chain reaction
critical mass

Section 20.8

mass defect
nuclear binding energy

Section 20.9

nuclear fusion

Section 20.10

transmutation
linear accelerator
cyclotron

Section 20.11

exposure
dose
biological effectiveness factor (RBE)
rem

Section 20.12

radiotracer

positron emission tomography (PET)

Key Concepts

Diagnosing Appendicitis (20.1)

- Radioactivity is the emission of subatomic particles or energetic electromagnetic radiation by the nuclei of certain atoms.
- Because some of these emissions can pass through matter, radioactivity is useful in medicine and many other areas of study.

The Discovery of Radioactivity (20.2)

- Antoine-Henri Becquerel discovered radioactivity when he found that uranium causes a photographic exposure in the absence of light.
- Marie Sklodowska Curie later determined that this phenomenon was not unique to uranium, and she began calling the rays that produced the exposure radioactivity. Curie also discovered two new elements, polonium and radium.

Types of Radioactivity (20.3)

- The major types of natural radioactivity are alpha (α) decay, beta (β) decay, gamma (γ) ray emission, and positron emission.
- Alpha radiation is helium nuclei. Beta particles are electrons. Gamma rays are electromagnetic radiation of very high energy. Positrons are the antiparticles of electrons.
- A nucleus may absorb one of its orbital electrons in a process called electron capture.
- We can represent each radioactive process with a nuclear equation that illustrates how the parent nuclide changes into the daughter nuclide. In a nuclear equation, although the specific types of atoms may not balance, the atomic numbers and mass numbers must.
- Each type of radioactivity has a different ionizing and penetrating power. These values are inversely related; a particle with a higher ionizing power has a lower penetrating power. Alpha particles are the most massive and have the highest ionizing power, followed by beta particles and positrons, which are equivalent in their ionizing power. Gamma rays have the lowest ionizing power.

The Valley of Stability: Predicting the Type of Radioactivity (20.4)

- The stability of a nucleus, and therefore the probability that it will undergo radioactive decay, depends largely on two factors. The first is the ratio of neutrons to protons (N/Z), because neutrons provide a strong force that overcomes the electromagnetic repulsions between the positive protons. This ratio is one for smaller elements but becomes greater than one for larger elements. The second factor related to nuclei stability is a concept known as magic numbers; certain numbers of nucleons are more stable than others.

Detecting Radioactivity (20.5)

- Radiation detectors determine the quantity of radioactivity in an area or sample.
- Thermoluminescent dosimeters employ salt crystals for detection of radiation; such detectors do not provide an instantaneous reading.
- Two detectors that instantly register the amount of radiation are the Geiger-Müller counter, which uses the ionization of argon by radiation to produce an electrical signal, and the scintillation counter, which uses the emission of light induced by radiation.

The Kinetics of Radioactive Decay and Radiometric Dating (20.6)

- All radioactive elements decay according to first-order kinetics (Chapter 14); the half-life equation and the

integrated rate law for radioactive decay are derived from the first-order rate laws.
- The kinetics of radioactive decay is used to date objects and artifacts. The age of materials that were once part of living organisms is measured by carbon-14 dating. The age of ancient rocks and even Earth itself is determined by uranium/lead dating.

The Discovery of Fission: The Atomic Bomb and Nuclear Power (20.7)

- Fission is the splitting of an atom, such as uranium-235, into two atoms of lesser atomic weight.
- Because the fission of one uranium-235 atom releases enormous amounts of energy and produces neutrons that can split other uranium-235 atoms, the energy from these collective reactions can be harnessed in an atomic bomb or nuclear reactor.
- Nuclear power produces no air pollution and requires little mass to release lots of energy; however, there is always a danger of accidents, and it is difficult to dispose of nuclear waste.

Converting Mass to Energy: Mass Defect and Nuclear Binding Energy (20.8)

- In a nuclear fission reaction, mass is converted into energy.
- The difference in mass between a nuclide and the individual protons and neutrons that compose it is the mass defect, and the corresponding energy, calculated from Einstein's equation $E = mc^2$, is the nuclear binding energy.
- The stability of a nucleus is determined by the binding energy per nucleon, which increases up to mass number 60 and then decreases.

Nuclear Fusion: The Power of the Sun (20.9)

- Stars produce their energy by a process that is the opposite of fission: nuclear fusion, the combination of two light nuclei to form a heavier one.
- Modern nuclear weapons employ fusion. Although fusion has been examined as a possible method to produce electricity, experiments with hydrogen fusion have been more costly than productive.

Nuclear Transmutation and Transuranium Elements (20.10)

- Nuclear transmutation, the changing of one element to another element, has been used to create the transuranium elements, elements with atomic numbers greater than that of uranium.
- Two devices that accelerate particles to the high speeds necessary for transmutation reactions are the linear accelerator and the cyclotron. Both use alternating voltage to propel particles by electromagnetic forces.

The Effects of Radiation on Life (20.11)

- Acute radiation damage is caused by a large exposure to radiation for a short period of time. Lower radiation exposures may result in increased cancer risk because of damage to DNA. Genetic defects are caused by damage to the DNA of reproductive cells.
- The most effective unit of measurement for the amount of radiation absorbed is the rem, which takes into account the different penetrating and ionizing powers of the various types of radiation.

Radioactivity in Medicine and Other Applications (20.12)

- Radioactivity is central to the diagnosis of medical problems by means of radiotracers and positron emission tomography (PET). Both of these techniques can provide data about the appearance and metabolic activity of an organ or help locate a tumor.
- Radiation is employed to treat cancer because it kills cells. Radiation is also used to kill bacteria in foods and to control harmful insect populations.

Key Equations and Relationships

The First-Order Rate Law (20.6)

$$\text{rate} = kN$$

The Half-Life Equation (20.6)

$$t_{1/2} = \frac{0.693}{k} \quad k = \text{rate constant}$$

The Integrated Rate Law (20.6)

$$\ln \frac{N_t}{N_0} = -kt \quad N_t = \text{number of radioactive nuclei at time } t$$
$$N_0 = \text{initial number of radioactive nuclei}$$

Einstein's Energy–Mass Equation (20.8)

$$E = mc^2$$