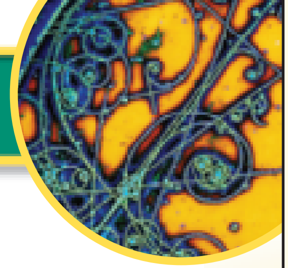


10.3 Artificial Transmutation

Reading Focus

Key Concepts

- How do artificial transmutations occur?
- How are transuranium elements produced?

Vocabulary

- transmutation
- transuranium elements
- quark

Reading Strategy

Monitoring Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. List two things you expect to learn. After reading, state what you learned about each item you listed.

What I Expect to Learn	What I Learned
a. ___?___	b. ___?___
c. ___?___	d. ___?___

During the Middle Ages, a number of people, like the ones shown in Figure 12, were obsessed with the idea of changing lead into gold. For centuries, these early scientists, known as alchemists, tried to use chemical reactions to make gold. But no matter how many recipes they tried, the alchemists only succeeded in making compounds that contained lead. What were they doing wrong?

Nuclear Reactions in the Laboratory

The alchemists were trying to achieve transmutation. **Transmutation** is the conversion of atoms of one element to atoms of another. It involves a nuclear change, not a chemical change.

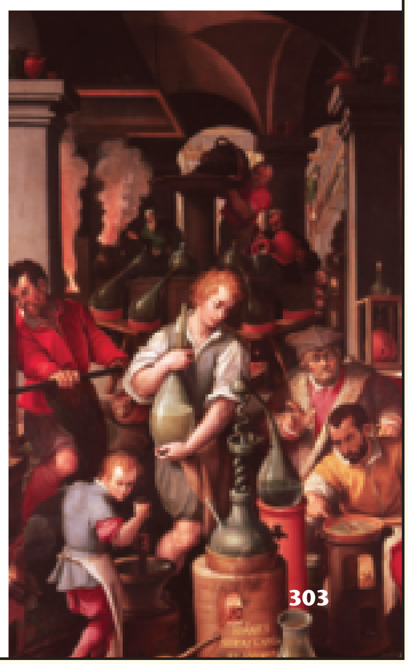
Nuclear decay is an example of a transmutation that occurs naturally. Transmutations can also be artificial. **Scientists can perform artificial transmutations by bombarding atomic nuclei with high-energy particles, such as protons, neutrons, or alpha particles.**

Early experiments involving artificial transmutation led to important clues about atomic structure. In 1919, a decade after he discovered the atomic nucleus, Ernest Rutherford performed the first artificial transmutation. Rutherford had been studying the effects of nuclear radiation on various gases. When Rutherford exposed nitrogen gas to alpha particles, he found that some of the alpha particles were absorbed by the nitrogen nuclei. Each newly formed nucleus then ejected a proton, leaving behind the isotope oxygen-17.

$$^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$$

Note that $^{1}_{1}\text{H}$ represents a proton. Rutherford's experiment provided evidence that the nucleus contains protons.

Figure 12 This painting of an alchemist's laboratory was made around 1570. The alchemists failed in their attempts to turn lead into gold.



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Section Resources

Print
- ***Reading and Study Workbook With Math Support,*** Section 10.3
- ***Transparencies,*** Section 10.3

Technology
- ***Interactive Textbook,*** Section 10.3
- ***Presentation Pro CD-ROM,*** Section 10.3

Section 10.3

1 FOCUS

Objectives

10.3.1 **Describe** and **identify** examples of transmutation.

10.3.2 **Describe** how transuranium elements are synthesized.

10.3.3 **Explain** how particle accelerators have been used in scientific research.

Reading Focus

Build Vocabulary L2

Paraphrase Ask students to write the vocabulary words on a sheet of paper. Instruct students to write a definition, in their own words, for each term as they encounter the term while going through the chapter. After writing their own definition, they should also write a complete sentence with the term.

Reading Strategy L2

Possible answers: **a.** Examples of artificial transmutation **b.** Rutherford's transmutation of nitrogen-14 into oxygen-17; the synthesis of neptunium-239 **c.** Uses of transuranium elements **d.** Smoke detectors (americium-241); space probes (plutonium-238)

2 INSTRUCT

Nuclear Reactions in the Laboratory

Address Misconceptions L2

The alchemists of the Middle Ages never succeeded in turning lead into gold. This doesn't mean, however, that it is impossible. Modern scientists, including Glenn Seaborg in 1980, have reportedly turned lead into gold. However, this has only been done with very minute amounts of lead. Challenge students to find out why scientists do not manufacture gold for profit using transmutation. *(The process of using nuclear reactions to change lead into gold is more expensive than the worth of the gold. Currently, it is cheaper to mine gold ore.)*
Verbal

Transuranium Elements

Quick Lab

Modeling Transmutation L2

Objective
After completing this activity, students will be able to
- balance equations that describe simple nuclear reactions.

Skills Focus Calculating, Using Models

Prep Time 5 minutes

Class Time 15 minutes

Safety Caution students to avoid dropping beads on the floor where they may lead to slips and falls.

Expected Outcome The products are carbon-13 and oxygen-17.

Analyze and Conclude
1. The missing products were carbon-13 and oxygen-17. The models should show that the total number of protons and neutrons on the left side of the equation is the same as on the right. After counting the number of green beads (protons) in the missing product isotope, its identity can be determined by referring to the periodic table. The mass number of the missing product isotope is the sum of its protons and neutrons.
2. Use the following equation to check students' models.
$^{27}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{14}Si + ^{1}_{1}H$
Visual

Build Reading Literacy L1

Visualize Refer to page **354D** in **Chapter 12**, which provides the guidelines for using visualization.

Have students keep their books closed. Tell them to listen carefully while you read the paragraph about synthesizing neptunium. Ask students to describe how they visualize what happens in the transmutation. Then, ask students to work in pairs and discuss how they visualized the process.
Visual

Quick Lab

Modeling Transmutation

Materials

periodic table, 2 sheets of unlined white paper, 32 green beads, 32 purple beads

Procedure

1. Use the periodic table to complete the following nuclear reaction. Then, write it on one of the sheets of paper.

$$^{10}_{5}B + ^{4}_{2}He \rightarrow ^{A}_{Z}X + ^{1}_{1}H$$

2. Count the number of protons and neutrons present in each reactant and product.
3. Using the green beads to represent protons and the purple beads to represent neutrons, make a model of each reactant and product below its symbol on the sheet of paper.
4. Repeat Steps 1 to 3 using the following nuclear reaction and the second sheet of paper.

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{A}_{Z}X + ^{1}_{1}H$$

Analyze and Conclude

1. **Applying Concepts** What was the missing product in each of the equations? How did you know what the missing product was?
2. **Using Models** Make a model of the nuclear reaction between an alpha particle and an atom of aluminium-27. (*Hint:* One of the two products is a proton.)

Transuranium Elements

Elements with atomic numbers greater than 92 (uranium) are called **transuranium elements.** All transuranium elements are radioactive, and they are generally not found in nature. **Scientists can synthesize a transuranium element by the artificial transmutation of a lighter element.**

Neptunium was the first transuranium element synthesized. In 1940, scientists at the University of California, Berkeley, bombarded uranium-238 with neutrons, producing uranium-239. The uranium-239 underwent beta decay to form neptunium-239.

$$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$$

Although most transuranium elements have only been produced for research, some are synthesized for industrial or consumer use. For example, americium-241 is a transuranium element used in smoke detectors. As americium-241 decays, it emits alpha radiation. This radiation ionizes the air inside a smoke detector to allow an electric current to flow. When smoke enters the smoke detector, it disrupts the current and the alarm goes off. Another useful transuranium element is plutonium-238. Figure 13 shows a space probe that runs on electrical energy generated by the decay of plutonium-238.

Reading Checkpoint *What is a transuranium element?*

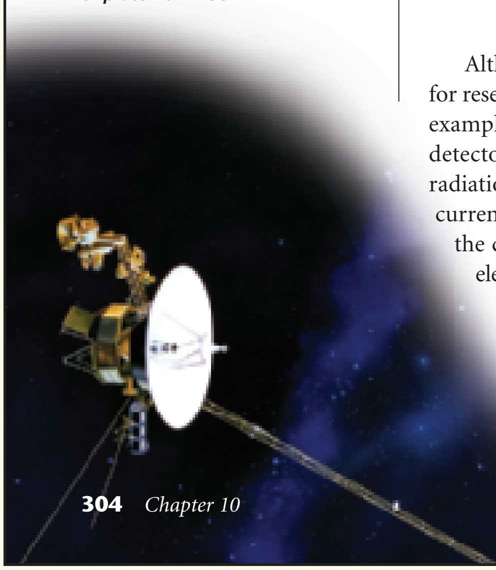

Figure 13 In 1977, the National Aeronautics and Space Administration (NASA) launched two identical spacecraft, Voyager 1 and Voyager 2. These spacecraft, which are still exploring the outer solar system, are powered by the alpha decay of plutonium-238. **Inferring** ***What isotope is produced by the alpha decay of plutonium-238?***

304 *Chapter 10*

Customize for Inclusion Students

Gifted
Challenge students to find the names of different types of subatomic particles besides protons, neutrons, and electrons. For example, have them research the six types of quarks. *(The six quarks are often called up, down, charmed, strange, top, and bottom.)* Then, have students find out when they were discovered and what properties are known about them. Have students create a presentation that explains the characteristics and discovery of several subatomic particles. *(Other subatomic particle types or categories include leptons, muons, tau particles, neutrinos, bosons, fermions, gluons, mesons, and baryons.)*

Particle Accelerators

In Rutherford's transmutation experiment, the radioactive element radium was used as a source of alpha particles. However, sometimes transmutations will not occur unless the bombarding particles are moving at extremely high speeds. In order to perform such transmutations, scientists use devices called particle accelerators. In a particle accelerator, charged particles can be accelerated to speeds very close to the speed of light. The fast-moving particles are guided toward a target, where they collide with atomic nuclei. With the help of particle accelerators, scientists have produced more than 3000 different isotopes.

Scientists also conduct collision experiments in order to study nuclear structure. Since the proton, neutron, and electron were discovered, more than 200 different subatomic particles have been detected. According to the current model of the atom, protons and neutrons are made up of even smaller particles called quarks. A **quark** is a subatomic particle theorized to be among the basic units of matter. Both protons and neutrons belong to a class of particles that are made up of three quarks. Six types of quarks are currently thought to exist. Two of these types were discovered at Fermi National Accelerator Laboratory, also known as Fermilab. Figure 14 shows one of the devices used at Fermilab to detect subatomic particles.

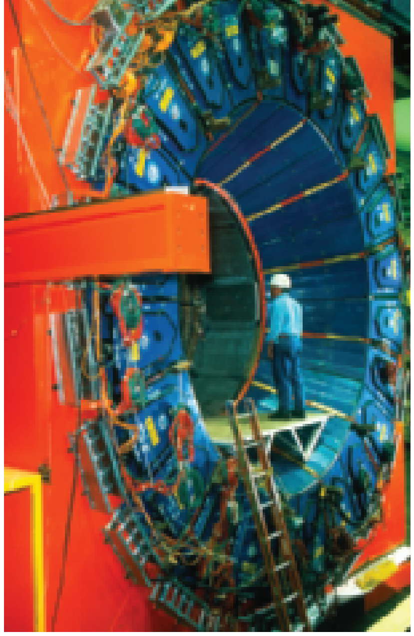

Figure 14 This particle detector records subatomic particles produced in the Tevatron, the most powerful particle accelerator in the United States. The Tevatron is located at Fermilab in Batavia, Illinois.

Section 10.3 Assessment

Reviewing Concepts

1. How do scientists perform artificial transmutations?
2. How are transuranium elements produced?
3. How does artificial transmutation differ from nuclear decay?
4. Write the equation for the transmutation that occurs when an alpha particle combines with an oxygen-16 atom, emitting a proton.
5. Does fermium-257 undergo nuclear decay? Explain.

Critical Thinking

6. **Predicting** Bombarding a lithium-6 atom with a neutron produces helium-4 and another particle. What is that particle?
7. **Predicting** Curium was first synthesized by bombarding a target isotope with alpha particles, which produced curium-242 and a neutron. What was the target isotope? (*Hint:* Use the symbol $^{1}_{0}n$ to represent a neutron.)
8. **Inferring** Why can't the transuranium elements be made by exposing other elements to naturally occurring alpha radiation?

Writing in Science

Summary Write a brief summary of the first artificial transmutation, performed by Ernest Rutherford. (*Hint:* Your summary should describe an example of a nuclear reaction.)

Section 10.3 Assessment

1. By bombarding atomic nuclei with high-energy particles, such as protons, neutrons, or alpha particles
2. By the artificial transmutation of lighter elements
3. Artificial transmutation is a nonnatural process in which a nucleus is bombarded with high-energy particles. Nuclear decay is a natural process in which an unstable nucleus emits charged particles and/or energy.
4. $^{16}_{8}O + ^{4}_{2}He \longrightarrow ^{19}_{9}F + ^{1}_{1}H$
5. Fermium-257, with an atomic number of 100, is a transuranium element and therefore undergoes nuclear decay.
6. Hydrogen-3
7. Plutonium-239
8. Because naturally occurring alpha particles do not have enough energy to be used in the synthesis of transuranium elements. The synthesis of transuranium elements requires high-energy particles.

Particle Accelerators

Build Science Skills L2

Inferring Ask students to read the first paragraph of Particle Accelerators. Ask, **What evidence supports the claim that most transuranium elements can exist only when atoms are bombarded with particles at very high speeds?** *(Transuranium elements generally do not occur in nature, so the conditions under which they are formed are not likely to be found in nature. Most transuranium elements have been produced only under conditions that can be achieved by using a particle accelerator.)*
Logical

3 ASSESS

Evaluate Understanding L2

Ask students to write three completed equations for transmutations. Have students take turns giving the reactants for the equation while another student determines the product with the correct number of protons and neutrons for each transmutation.

Reteach L1

Have students look at the transmutation equations in the section and ask them to explain how transmutation differs from nuclear decay.

Writing in Science

Rutherford performed the first artificial transmutation while studying the effects of nuclear radiation on gases. After he exposed nitrogen gas to alpha radiation, he observed that some of the alpha particles were temporarily absorbed by the nitrogen nuclei. Each newly formed nucleus then ejected a proton, leaving behind oxygen-17. In this transmutation, nitrogen-14 was converted into oxygen-17.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 10.3.

Answer to . . .

Figure 13 *Uranium-234. The equation is:*

$$^{238}_{94}Pu \longrightarrow ^{234}_{92}U + ^{4}_{2}He$$

Reading Checkpoint *An element with an atomic number greater than 92*