25.3 Fission and Fusion of Atomic Nuclei

Objectives
25.3.1 Describe what happens in a nuclear chain reaction.
25.3.2 Explain the role of water in the storage of spent fuel rods.
25.3.3 Distinguish fission reactions from fusion reactions.

Guide for Reading

Build Vocabulary

Graphic Organizers Have students draw a concept map that correctly relates the vocabulary terms for this section.

Reading Strategy
Preview Before students read the section in detail, have them preview the section headings, visuals, and boldfaced material.

INSTRUCT

Connecting to Your World

Have students study the photograph and read the text that opens the section. Explain that the sun contains hydrogen nuclei. Ask, In which state of matter do these hydrogen nuclei exist? (plasma) Describe a hydrogen nucleus. (a proton) Explain that protons can combine to produce helium nuclei. Ask, How is the energy of the sun produced? (Energy is released during the formation of helium nuclei.)

Nuclear Fission

Discuss

Ask, What is the general meaning of fission? (An object splits into smaller parts.) What is the general meaning of fusion? (Objects combine into a larger whole.) Explain that these terms have more precise meanings when applied to nuclear reactions but still include the concepts of fragmentation and merging.

Figure 25.10 In nuclear fission, a uranium-235 nucleus breaks into two smaller nuclei and releases neutrons. Predicting What happens when the released neutrons strike other uranium-235 nuclei?

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Section Resources

Print
• Guided Reading and Study Workbook, Section 25.3
• Core Teaching Resources, Section 25.3 Review
• Transparency, T293

Technology
• Interactive Textbook with ChemASAP, Animation 30, Assessment 25.3
Fission can be controlled so energy is released more slowly. Nuclear reactors, such as the one illustrated in Figure 25.11, use controlled fission to produce useful energy. In the controlled fission reaction within a nuclear reactor, much of the energy generated is in the form of heat. A coolant fluid, usually liquid sodium or water, removes the heat from the reactor core. The heat is used to generate steam, which drives a turbine that in turn generates electricity. The control of fission in a nuclear reactor involves two steps, neutron moderation and neutron absorption.

**Neutron Moderation** Neutron moderation is a process that slows down neutrons so the reactor fuel (uranium-235 or plutonium-239) captures them to continue the chain reaction. Moderation is necessary because most of the neutrons produced move so fast that they will pass right through a nucleus without being absorbed. Water and carbon in the form of graphite are good moderators.

**Neutron Absorption** To prevent the chain reaction from going too fast, some of the slowed neutrons must be trapped before they hit fissionable atoms. Neutron absorption is a process that decreases the number of slow-moving neutrons. Control rods, made of a material such as cadmium, are used to absorb neutrons. When the control rods extend almost all the way into the reactor core, they absorb many neutrons, and fission occurs slowly. As the rods are pulled out, they absorb fewer neutrons and the fission process speeds up. If the chain reaction were to go too fast, heat might be produced faster than the coolant could remove it. In this case, the reactor core would overheat, which could lead to mechanical failure and release of radioactive materials into the atmosphere. Ultimately, a meltdown of the reactor core might occur.

**Checkpoint** Why must neutrons in a reactor be slowed down?

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**Differentiated Instruction**

**English Learners**

Have students write the definitions of fission and fusion in their notebooks in their native language and in English. Have them prepare a table, complete with sample reactions, describing the characteristics of fission and fusion processes in nuclear chemistry.

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**Answers to...**

**Checkpoint** so the reactor fuel can capture them to continue the chain reaction.
Section 25.3 (continued)

Nuclear Waste

Discuss

Have students compare and contrast nuclear fission and nuclear fusion. Ask students to describe the advantages and disadvantages of each type of process as a means to meet future energy needs. Ask, What types of technical hurdles remain to be solved in order to utilize the energy produced by nuclear fusion? (Accept any reasonable answer, such as containment of the reaction.)

Relate

Explain that the wastes produced in fission reactors contain isotopes with half-lives measured in the thousands or hundreds of thousands of years. Many proposals for storing or disposing of these wastes involve methods and materials that may be highly unsuitable. For example, the placement of wastes in thick drums that would then be sunk in the oceans—one suggested method—may contain the waste for only decades or a few centuries. The containers would begin to leak long before the contents were safe. The disposal problem has led some people to propose permanent abandonment of nuclear reactors as sources of energy. After students read the text, lead a discussion on the pros and cons of using nuclear energy from fission reactors.

Figure 25.12 Racks at the bottom of this pool contain spent fuel rods. The blue glow is from beta particles that the rods emit into the water.

Facts and Figures

Nuclear Waste and Nuclear Power

Concerns about nuclear wastes are magnified by the timeframe during which the wastes will be hazardous. As of 1997, 440 nuclear power plants were in operation worldwide and about 30 countries got some of their electricity from nuclear power stations. In France, for example, 75% of the electricity is generated by nuclear power. By contrast, only about 20% of electricity generated in the United States comes from nuclear power plants. The DOE is responsible for cleaning up 130 nuclear sites and safely managing their waste. The sites include locations where uranium was milled, research labs, and former nuclear weapons production facilities. Have students research how the cleanups are progressing.
Nuclear Fusion

The sun, directly and indirectly, is the source of most energy used on Earth. The energy released by the sun results from nuclear fusion. Fusion occurs when nuclei combine to produce a nucleus of greater mass. In solar fusion, hydrogen nuclei (protons) fuse to make helium nuclei. Figure 25.13 shows that the reaction also produces two positrons. Fusion reactions, in which small nuclei combine, release much more energy than fission reactions, in which large nuclei split. However, fusion reactions occur only at very high temperatures—in excess of 40,000,000°C.

The use of controlled nuclear fusion as an energy source on Earth is appealing. The potential fuels are inexpensive and readily available. One reaction that scientists are studying is the combination of a deuterium (hydrogen-2) nucleus and a tritium (hydrogen-3) nucleus to form a helium nucleus.

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^2\text{H} + ^3\text{H} \rightarrow ^3\text{He} + ^0\text{n} + \text{energy}
\]

The problems with fusion lie in achieving the high temperatures necessary to start the reaction and in containing the reaction once it has started. The high temperatures required to initiate fusion reactions have been achieved by using a fission bomb. Such a bomb is the triggering device used for setting off a hydrogen bomb, which is an uncontrolled-fusion device. Such a process is clearly of no use, however, as a controlled generator of power.

25.3 Section Assessment

15. Key Concept Explain what happens in a nuclear chain reaction.
16. Key Concept Why are spent fuel rods from a nuclear reactor stored in water?
17. Key Concept How are fusion reactions different from fission reactions?
18. What does nuclear moderation accomplish in a nuclear reactor?
19. What is the source of the radioactive nuclei present in spent fuel rods?
20. Assuming technical problems could be overcome, what are some advantages to using a fusion reactor to produce electricity?

25.3 Section Assessment

15. Neutrons produced by fissionable atoms react with other fissionable atoms, producing more neutrons that react with other fissionable atoms.
17. Fission reactions involve splitting nuclei. In fusion reactions, small nuclei combine and release much more energy.
18. Slows down neutrons
19. Unused nuclear fuel and fission products
20. Potential fuels are inexpensive and readily available.
**Dating a Fossil**

Discuss with students the limits of using carbon-14 to date fossils. First, some organic material must be present, as the material tested must be from an organism that once lived. If only an imprint remains and all organic material is gone, therefore, carbon-14 cannot be used in dating the fossil. Second, after a certain time, so little carbon-14 remains that it cannot be detected. Experts disagree as to what this age is, but it is commonly accepted that carbon-14 dating cannot be used reliably on objects that are more than 75,000 years old. Ask, **To the nearest whole number, how many half-lives of carbon-14 is 75,000 years?** (75,000 years/5730 years per half-life = 13 half-lives.) **What percent of the carbon-14 remains after this number of half lives?** (0.0012%) 

**Calculating** An unearthed wooden tool was found to have only 50% of the carbon-14 content of a sample of living wood. How old is the wooden tool?

Archaeology Archaeologists study the life and culture of the past, especially ancient peoples, by excavating ancient cities, relics, and artifacts.

The Wooly Mammoth The fossil remains of a woolly mammoth are found in Pleistocene deposits (the Pleistocene epoch was from 2,500,000 to 10,000 years ago). The abundance of well-preserved carcasses in the permanently frozen ground of Siberia have provided much information about these extinct animals.

**Facts and Figures**

**Relative Dating**

Fossils can also be dated by relating them to known geological events. For example, during a large volcanic eruption, vast amounts of volcanic ash are spread over large areas of the surrounding area. This ash will settle and eventually become a distinctive clay layer. Any fossil in or near this layer can be dated according to the date of the event that formed the layer.
Use Visuals
Note in the large photo that the fish fossil is in a distinct rock layer. Ask, What methods other than carbon-14 dating might be used to date the fossil? (Answers will vary but might include looking for other fossils in the layer and dating them.) Discuss how organisms found in the same rock layer probably formed at the same time. Some of these fossils might be dated by using carbon-14, and others might be from organisms that existed only during a known, short period of time.

Relate
Ask students to relate the half-lives in Table 25.3 on page 805 to the usefulness of isotopes in dating materials. For example, uranium-238 is used to date rocks that are quite old. If U-238 were used to date a sample that is only 50,000 years old, not enough of the U-238 would have decayed for the change to be noticed. Ask, Which of the radioisotopes listed in the table might be used to date a rock that is 20 million years old? (Answers will vary, but students might suggest potassium-40.)

Differentiated Instruction
Gifted and Talented
Have students write down the exact procedure used to work problems involving whole-number half-lives. Then have them use scientific calculators to expand this procedure to include partial half-lives. Provide students with problems to work that involve partial half-lives. Examples might include problems such as the following: A fossil was found to contain 60% of its original carbon-14. How old is the fossil? \( k = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{5,730 \text{ yr}} = 1.21 \times 10^{-4} \text{ yr}^{-1} ; t = \frac{1}{k} \ln \frac{A_0}{A_t} = (1/1.21 \times 10^{-4} \text{ yr}^{-1}) \ln(1/0.60) = 4,200 \text{ yr} \)

Answers to...
Calculating 5,730 years.