1 FOCUS

Objectives

10.4.1 **Compare** and **contrast** nuclear forces.
10.4.2 **Describe** the process of nuclear fission.
10.4.3 **Explain** how nuclear reactors are used to produce energy.
10.4.4 **Describe** the process of nuclear fusion.

Reading Focus

Build Vocabulary

L2

Word-Part Analysis Remind students that they can use what they know about word parts to figure out the meanings of words. Point out *fission* and *fusion.* Tell students that *-ion* means "the act of" or "the result of an act." Explain that *fiss-* comes from a Latin word meaning "split" and that *fus-* comes from another Latin word meaning "melted."

Reading Strategy

L2

a. Is the splitting of a large nucleus into two smaller fragments **b.** Widely used as an energy source **c.** Is the fusing of two small nuclei into one larger nucleus **d.** Still being researched and developed as an alternate energy source

2 INSTRUCT

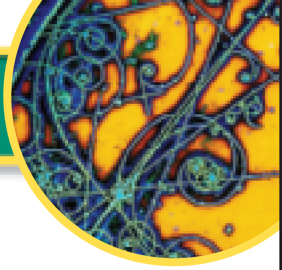
Nuclear Forces

Use Visuals

L2

Figure 15 Have students carefully examine the illustration. Ask, **Why are there no electric forces between protons and neutrons?** *(Neutrons have no charge.)* **What force is able to overcome the electrostatic forces of repulsion that exist between protons in a nucleus?** *(The strong nuclear force)*
Visual, Logical

10.4 Fission and Fusion



Reading Focus

Key Concepts

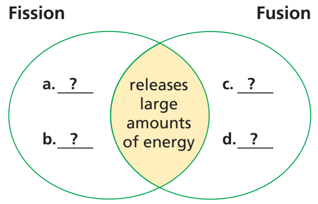
- Under what conditions does the strong nuclear force overcome electric forces in the nucleus?
- What property of fission makes it so useful?

Vocabulary

- strong nuclear force
- fission
- chain reaction
- critical mass
- fusion
- plasma

Reading Strategy

Comparing and Contrasting Copy the Venn diagram below. As you read, contrast fission and fusion by listing the ways they differ.



Alternative energy sources may someday replace fossil fuels such as coal and oil. One alternative energy source that is widely used today is nuclear energy. Nuclear energy is the energy released by nuclear reactions.

Shortly after the discovery of radioactivity, scientists realized that atomic nuclei contained vast amounts of energy. By the late 1930s, scientists discovered that transmutations involved more than just the conversion of one element into another—they also involved the conversion of mass into energy.

Nuclear Forces

What holds the nucleus together? Remember that the protons in the nucleus are all positively charged, so they tend to repel one another. Clearly, there must be an attractive force that binds the particles of the nucleus. Otherwise, the protons would simply push one another away.

The **strong nuclear force** is the attractive force that binds protons and neutrons together in the nucleus. Because the strong nuclear force does not depend on charge, it acts among protons, among neutrons, and among protons and neutrons. **Over very short distances, the strong nuclear force is much greater than the electric forces among protons.** For example, at distances as short as the width of a proton, the strong nuclear force is more than 100 times greater than the electric force that repels protons. However, the strong nuclear force quickly weakens as protons and neutrons get farther apart. Figure 15 summarizes the forces acting on protons and neutrons in the nucleus.

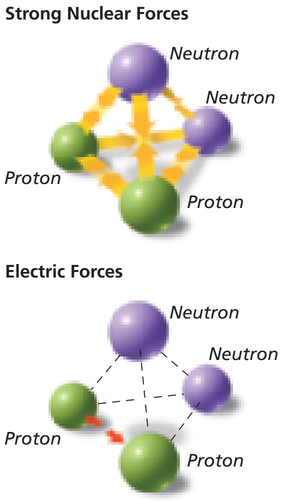


Figure 15 Two kinds of forces act upon particles in the nucleus. Strong nuclear forces, which are attractive, act on protons and neutrons alike. Electric forces in the nucleus are repulsive, and act only among protons. **Using Models** *What atomic nucleus is represented above?*

Section Resources

Print
- ***Reading and Study Workbook With Math Support,*** Section 10.4
- ***Transparencies,*** Section 10.4

Technology
- ***Interactive Textbook,*** Section 10.4
- ***Presentation Pro CD-ROM,*** Section 10.4
- ***Go Online,*** NSTA SciLinks, Fission

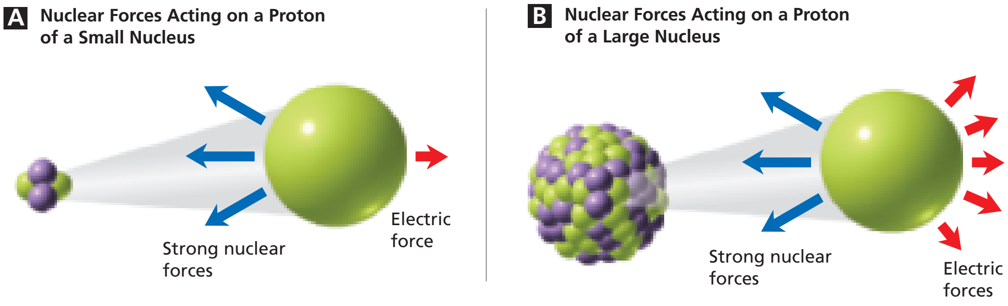


Figure 16 The size of a nucleus affects how strongly it is bound together. **A** In a nucleus containing two protons and two neutrons, the strong nuclear forces easily overcome the electric force between the protons. **B** In a nucleus containing many protons and neutrons, the larger number of electric forces makes the nucleus less stable.

The Effect of Size on Nuclear Forces Electric forces in atomic nuclei depend on the number of protons. The greater the number of protons in a nucleus, the greater is the electric force that repels those protons. So in larger nuclei, the repulsive electric force is stronger than in smaller nuclei.

The effect of size on the strong nuclear force is more complicated. On one hand, the more protons and neutrons there are in a nucleus, the more possibilities there are for strong nuclear force attractions. However, as the size of the nucleus increases, the average distance between protons and neutrons increases. Because the strong nuclear force only acts over short ranges, the possibility of many attractions is never realized in a large nucleus. As a result, the strong nuclear force felt by one proton or neutron in a large nucleus is about the same as in a small nucleus, as shown in Figure 16.

Unstable Nuclei A nucleus becomes unstable, or radioactive, when the strong nuclear force can no longer overcome the repulsive electric forces among protons. While the strong nuclear force does not increase with the size of the nucleus, the electric forces do. There is, therefore, a point beyond which all elements are radioactive. All nuclei with more than 83 protons are radioactive.

Fission

In 1938, two German chemists, Otto Hahn and Fritz Strassman, performed a series of important transmutation experiments. By bombarding uranium-235 with high-energy neutrons, Hahn and Strassman hoped to produce more massive elements. Instead, their experiments produced isotopes of a smaller element, barium. Unable to explain their data, Hahn and Strassman turned to a colleague for help. In 1939, Lise Meitner, shown in Figure 17, and Otto Frisch, another physicist, offered a groundbreaking explanation for the experiments. The uranium-235 nuclei had been broken into smaller fragments. Hahn and Strassman had demonstrated nuclear fission. **Fission** is the splitting of an atomic nucleus into two smaller parts.

Figure 17 Austrian physicist Lise Meitner (1878–1968), shown here, and Otto Frisch were the first scientists to describe nuclear fission. Meitner correctly predicted that fission releases large amounts of energy.

Fission

Build Reading Literacy L1

Sequence Refer to page **290D** in this chapter, which provides guidelines for using a sequence.

Have students read the text on nuclear fission on pp. 309 and 310. Then, have students do the following:

1. Ask students to make a sketch similar to Figure 18. Tell students that they can use circles to represent the nuclei. Students should use larger circles to represent the uranium nuclei.

2. Have students label and describe what happens as a neutron strikes the uranium-235 nucleus and the steps that follow. Start with the neutron as Step 1. Each following step should be numbered in sequence.

3. Students' sketches should include as much detail as they find from the text, Figure 18, and the caption.

Visual, Portfolio

Integrate Language Arts L2

Tell students that scientists in several countries were instrumental to the understanding of nuclear fission. The English scientist James Chadwick discovered the neutron in 1932. In 1934, Italian scientists led by Enrico Fermi conducted experiments involving the slow-neutron bombardment of uranium. Fermi's results prompted German chemists Otto Hahn and Fritz Strassman, and Austrian physicist Lise Meitner, to further investigate the products formed when uranium is bombarded with neutrons. Meitner and Otto Frisch built on the results of this research and in 1939 described the fission process. Have students write a brief biography of one of the scientists who contributed to the understanding of nuclear fission.

Verbal

Customize for English Language Learners

Cloze Reading

Select and copy an appropriate paragraph from one of the sections, such as the second paragraph on p. 309. Leave the first and last sentences intact, since they are usually the introductory and concluding sentences. For the sentences in the middle, remove key vocabulary words and replace them with a blank. For example, leave blanks for *protons* and *neutrons* in the second sentence of this paragraph, for *proton* in the third sentence, and for *short* in the fourth sentence. Have students read the paragraph and fill in the blanks with the appropriate words. You may create a word bank for students to use when filling in the blanks.

Answer to . . .

Figure 15 *A helium nucleus*

Use Visuals **L1**

Figures 18 and 19 Ask students to look at both figures. Ask, **Why do you think the uranium-236 atom is missing in Figure 19?** *(Uranium-236 is very unstable and does not last long before it splits into two smaller nuclei.)* **What happens to the amount of energy released during a chain reaction?** *(The amount of energy released increases as the chain reaction proceeds.)* **Visual**

Build Math Skills **L1**

Formulas and Equations Ask students to examine the mass-energy equation and determine the units of measurement that E is equivalent to. Remind them that the SI units for mass and speed are, respectively, kg and m/s. (Units of E are equivalent to kg × $(m/s)^2$.) Also ask students to determine what the formula would be for calculating c. *($c = \sqrt{E/m}$)* **Logical**

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

Go Online
NSTA SCILINKS

Download a worksheet on fission for students to complete, and find additional teacher support from NSTA SciLinks.

Figure 18 The fission of uranium-235 yields smaller nuclei, neutrons, and energy. The nuclear equation for this reaction can be written as follows.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \longrightarrow$$
$$^{91}_{36}\text{Kr} + ^{142}_{56}\text{Ba} + 3\,^{1}_{0}\text{n} + \text{energy}$$

Comparing and Contrasting ***How does fission differ from nuclear decay?***

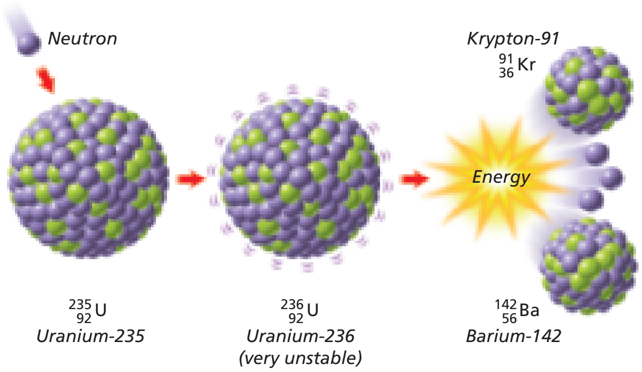


Figure 18 illustrates the fission of a uranium-235 nucleus. Notice that one of the products of the reaction is energy. **In nuclear fission, tremendous amounts of energy can be produced from very small amounts of mass.** For example, the nuclear energy released by the fission of 1 kilogram of uranium-235 is equivalent to the chemical energy produced by burning more than 17,000 kilograms of coal.

Converting Mass Into Energy In the nuclear equation shown in Figure 18, the mass numbers on the left equal the mass numbers on the right. Yet when the fission of uranium-235 is carried out, about 0.1 percent of the mass of the reactants is lost during the reaction. This "lost" mass is converted into energy.

In 1905, more than 30 years before the discovery of fission, physicist Albert Einstein had introduced the mass-energy equation. It describes how mass and energy are related.

Mass–Energy Equation

$$E = mc^2$$

In the mass-energy equation, E represents energy, m represents mass, and c represents the speed of light (3.0×10^8 m/s). The conversion of a small amount of mass releases an enormous amount of energy. Likewise, a large amount of energy can be converted into a small amount of mass. The explosion of the first atomic bomb in 1945 offered a powerful demonstration of the mass-energy equation. The bomb contained 5 kilograms of plutonium-239. Fission of the plutonium produced an explosion that was equivalent to 18,600 tons of TNT.

Recall how the law of conservation of mass applied to chemical reactions. In nuclear reactions, however, the energies involved are much larger. To account for the conversion of mass into energy, a modified conservation law is used. According to the law of conservation of mass and energy, the total amount of mass and energy remains constant.

Go Online
NSTA SCILINKS

For: Links on fission
Visit: www.SciLinks.org
Web Code: ccn-1104

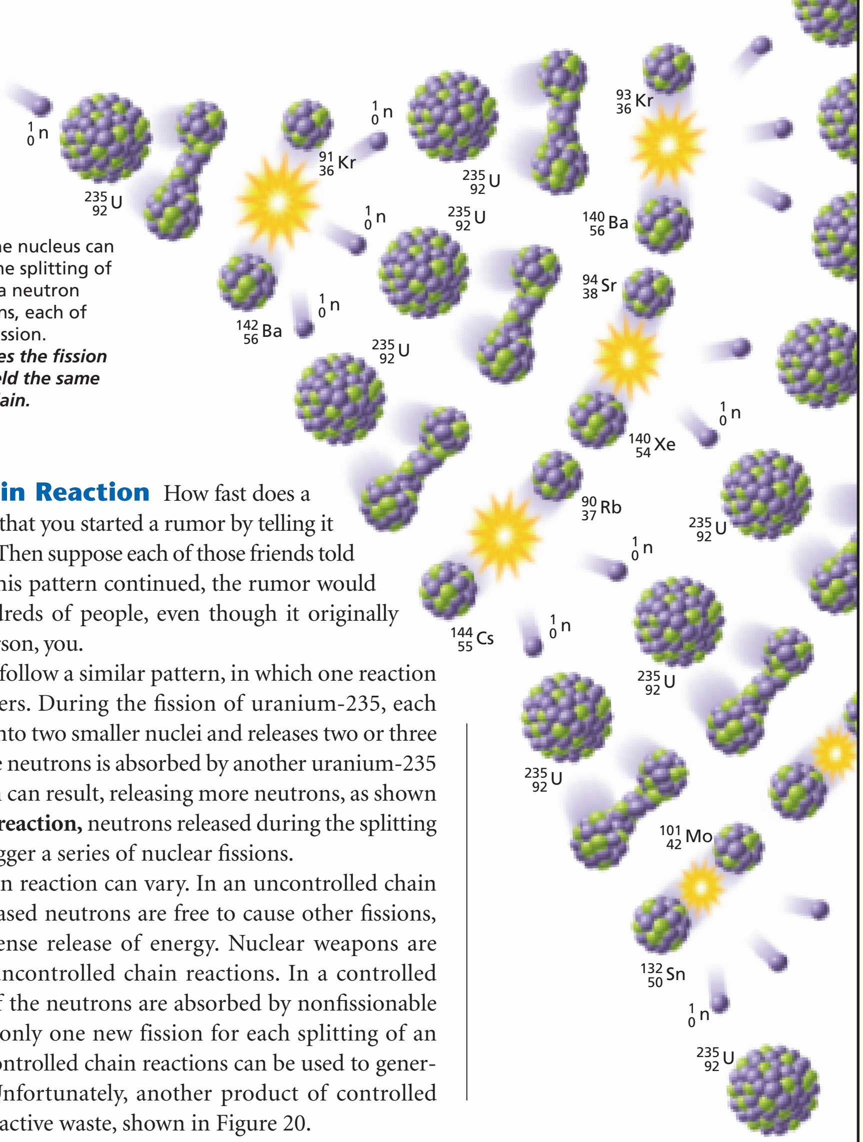


Figure 19 The fission of one nucleus can trigger a chain reaction. The splitting of a uranium-235 nucleus by a neutron yields two or three neutrons, each of which can cause another fission. **Interpreting Diagrams** ***Does the fission of uranium-235 always yield the same isotopes as products? Explain.***

Triggering a Chain Reaction How fast does a rumor spread? Imagine that you started a rumor by telling it to three of your friends. Then suppose each of those friends told three more friends. If this pattern continued, the rumor would quickly spread to hundreds of people, even though it originally started with just one person, you.

Nuclear fission can follow a similar pattern, in which one reaction leads to a series of others. During the fission of uranium-235, each reactant nucleus splits into two smaller nuclei and releases two or three neutrons. If one of these neutrons is absorbed by another uranium-235 nucleus, another fission can result, releasing more neutrons, as shown in Figure 19. In a **chain reaction,** neutrons released during the splitting of an initial nucleus trigger a series of nuclear fissions.

The speed of a chain reaction can vary. In an uncontrolled chain reaction, all of the released neutrons are free to cause other fissions, resulting in a fast, intense release of energy. Nuclear weapons are designed to produce uncontrolled chain reactions. In a controlled chain reaction, some of the neutrons are absorbed by nonfissionable materials, resulting in only one new fission for each splitting of an atom. The heat from controlled chain reactions can be used to generate electrical energy. Unfortunately, another product of controlled chain reactions is radioactive waste, shown in Figure 20.

In order to sustain a chain reaction, each nucleus that is split must produce, on average, one neutron that causes the fission of another nucleus. This condition corresponds to a specific mass of fissionable material, known as a critical mass. A **critical mass** is the smallest possible mass of a fissionable material that can sustain a chain reaction.

Reading Checkpoint ***What is a chain reaction?***

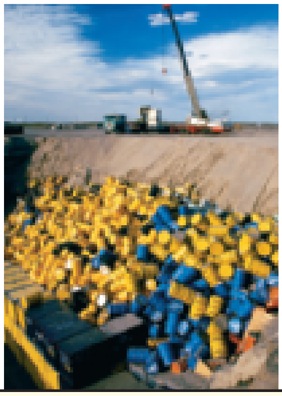


Figure 20 A crane lowers drums of radioactive waste into a landfill in Hanford, Washington.

Facts and Figures

Natural Nuclear Reactor In 1972 when Francis Perrin uncovered evidence of a "natural nuclear reactor" in mines in Gabon, Africa, other scientists questioned his findings. They wanted to know how a natural nuclear reactor could exist when it required precise engineering work to construct one.

Further study showed that the expected proportions of uranium-238 (99.3%) and uranium-235 (0.7%), were not present in the Gabon mines. There was much less uranium-235. Scientists used this data and calculated that 1.7 billion years ago, the proportion of uranium-235 was 3%, enough for nuclear fission. Underground water helped create the right conditions for a chain reaction. Scientists think the natural nuclear reaction continued intermittently for at least a million years until the uranium-235 was mostly used up.

Teacher Demo

Nuclear Processes

L2

Purpose Students observe a model of nuclear fission and fusion.

Materials bubble solution, 2 bubble wands

Procedure Dip the end of each wand into the solution and remove. Gently blow into the ring of each wand to make a bubble with a diameter a little larger than the ring, and catch the bubble on the wand. Bring the wands and the bubbles together. Press the bubbles together to form one large bubble, illustrating fusion. Pull the two frames farther apart to separate the bubble into two bubbles, one in each frame, simulating fission. When this is done a little faster small bubbles may be released, representing the released neutron. Discuss with students the strengths and weaknesses of this model.

Expected Outcome Students observe how to use bubbles to model nuclear fusion and nuclear fission. Students may point out that this demonstration does not model the neutron required to initiate fission.

Visual, Group

Answer to . . .

Figure 18 *Unlike nuclear decay, fission is generally not spontaneous. A neutron must be introduced in order for the fission of uranium-235 to occur. During the nuclear decay of uranium-235, however, no other reactants are necessary in order for the radioisotope to decay into thorium-231 and emit alpha radiation.*

Figure 19 *No. Fission of uranium-235 can produce a number of different combinations of product isotopes. Although fission results in the fragmentation of the nucleus into two parts, the composition of those two parts (and hence the number of neutrons released) can vary widely.*

Reading Checkpoint *A chain reaction is a nuclear reaction sequence in which neutrons released during the splitting of an initial nucleus trigger a series of nuclear fissions.*

SCIENCE and History

Nuclear Chemistry L2

Enrico Fermi and his research group achieved the first controlled nuclear chain reaction while the United States was fighting World War II. This was the first nuclear reactor. While this reactor was used for research, the main purpose of the reactor was to make plutonium for the atom bomb. After World War II, the U.S. population rose, and the growing population increased the demand for electricity. Scientists saw the potential of nuclear energy to help meet this demand. In 1951, electricity was produced using atomic power for the first time at a reactor in Idaho. The reactor produced enough electricity to light four light bulbs. Today, more than 400 nuclear power plants operate worldwide, with over 100 operating in the United States.

Have students research nuclear power plant safety and write a one-paragraph opinion about whether the benefits of nuclear power generation are worth the risks.
Verbal, Portfolio

Writing in Science

Possible answer: A number of groundbreaking scientific discoveries within the last 100 years have set the stage for nuclear energy. In 1905 (less than ten years after the discovery of radioactivity), Albert Einstein introduced his mass-energy equation, which described how very small amounts of mass could be converted into enormous amounts of energy. In 1938, Otto Hahn and Fritz Strassman performed the first nuclear fission (of uranium). A self-sustaining nuclear chain reaction was achieved just four years later. By 1951, scientists had developed nuclear fission into a promising source of electrical energy.
Verbal

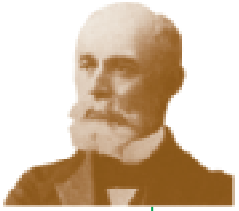
Nuclear Energy from Fission Today, nuclear power plants generate about 20 percent of the electricity in the United States. In a nuclear power plant, controlled fission of uranium-235 occurs in a vessel called a fission reactor.

Unlike power plants that burn fossil fuels, nuclear power plants do not emit air pollutants such as oxides of sulfur and nitrogen. However, nuclear power plants have their own safety and environmental issues. For example, workers in nuclear power plants need to wear protective clothing to reduce their exposure to nuclear radiation. In addition, the fission of uranium-235 produces many radioactive isotopes with half-lives of hundreds or thousands of years. This radioactive waste must be

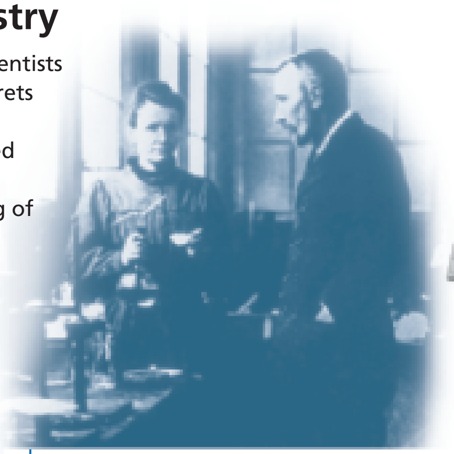
SCIENCE and History

Nuclear Chemistry

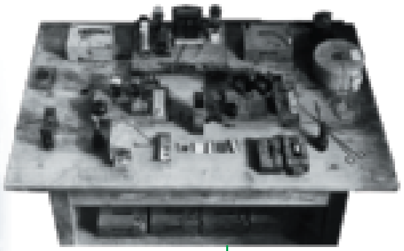
Over the last 100 years scientists have uncovered many secrets about the atomic nucleus. Developments have ranged from the synthesis of new elements to the harnessing of nuclear power as a viable energy source.



HENRI BECQUEREL



MARIE AND PIERRE CURIE AT WORK IN THEIR LABORATORY



EQUIPMENT USED BY HAHN AND STRASSMANN

1896 French scientist Antoine Henri Becquerel discovers radioactivity in uranium.

1898 Marie and Pierre Curie discover the radioactive elements radium and polonium. By making radium available to other scientists, the Curies helped advance the study of radioactivity.

1905 Albert Einstein's mass-energy equation, $E = mc^2$, provides the basis for nuclear power.

1932 First atom smasher (subatomic particle accelerator) is used by John Cockcroft and Ernest Walton.

1938 Germans Otto Hahn and Fritz Strassmann produce nuclear fission by bombarding uranium-235 atoms with neutrons.

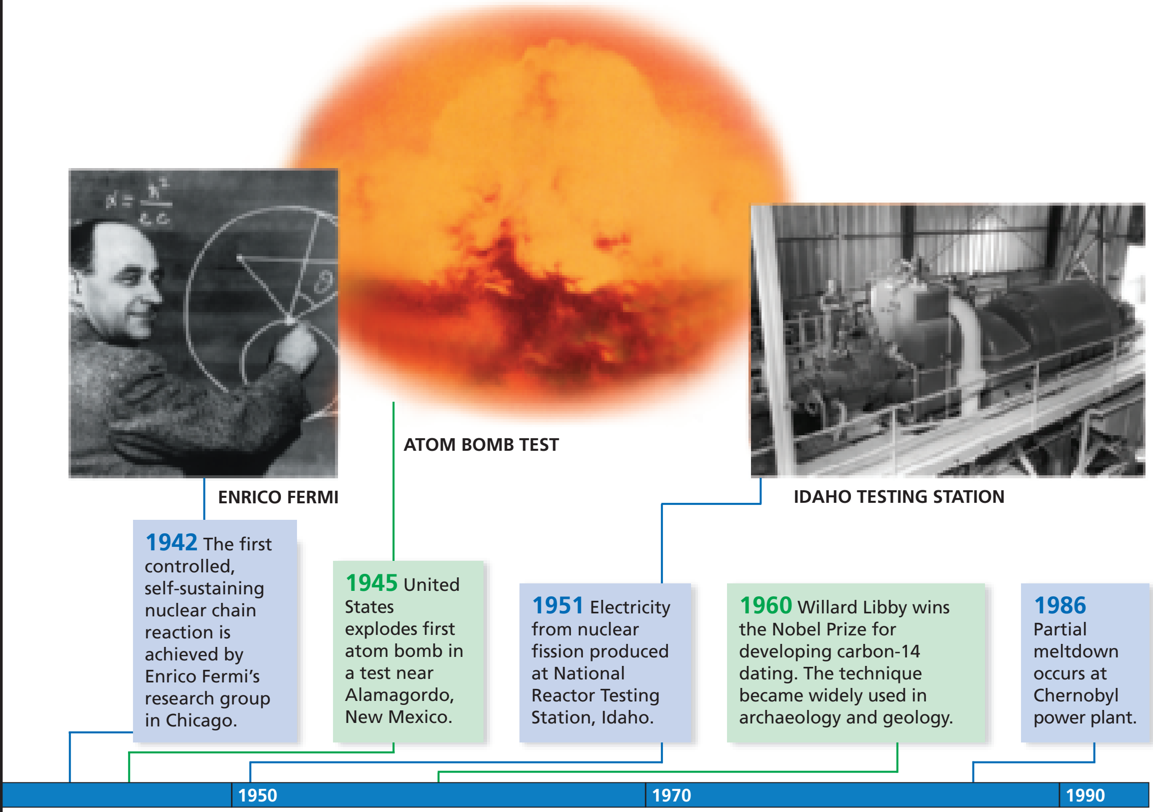
1890 1910 1930

isolated and stored so that it cannot harm people or contaminate the environment while it decays.

Another concern about nuclear power is that the operators of the plant could lose control of the reactor. For instance, if the reactor's cooling system failed, then a meltdown might occur. During a meltdown, the core of the reactor melts and radioactive material may be released. If the structure that houses the reactor is not secure, then the environment can become contaminated. In 1986, one of the reactors at the nuclear power station in Chernobyl, Ukraine, overheated during an experiment. A partial meltdown resulted, and large amounts of radioactive material were released into the atmosphere.

Writing in Science

Summary Write a paragraph about the history of nuclear energy based on some of the events in the time line below. (*Hint:* Before you write, use a flowchart to organize the events you wish to include.)



ENRICO FERMI

ATOM BOMB TEST

IDAHO TESTING STATION

1942 The first controlled, self-sustaining nuclear chain reaction is achieved by Enrico Fermi's research group in Chicago.

1945 United States explodes first atom bomb in a test near Alamagordo, New Mexico.

1951 Electricity from nuclear fission produced at National Reactor Testing Station, Idaho.

1960 Willard Libby wins the Nobel Prize for developing carbon-14 dating. The technique became widely used in archaeology and geology.

1986 Partial meltdown occurs at Chernobyl power plant.

Use Community Resources

L2

Ask students to find out what percentage of the power in their state comes from nuclear power plants. Encourage them to use library resources, such as the Internet, to find statistics. If your state does not receive power from nuclear power plants, instruct students to find that information for another state. Ask students to make a diagram and write a brief summary of their findings.

Interpersonal, Portfolio

HOW It Works

Nuclear Power Station

L2

Background

Uranium-235, the fissionable material used in nuclear power plants, makes up only about 0.7% of all uranium found in nature. In order for a nuclear reactor to operate, about 3% of the uranium in the fuel rods must be uranium-235. Samples of uranium must be enriched so that they contain this higher percentage of uranium-235.

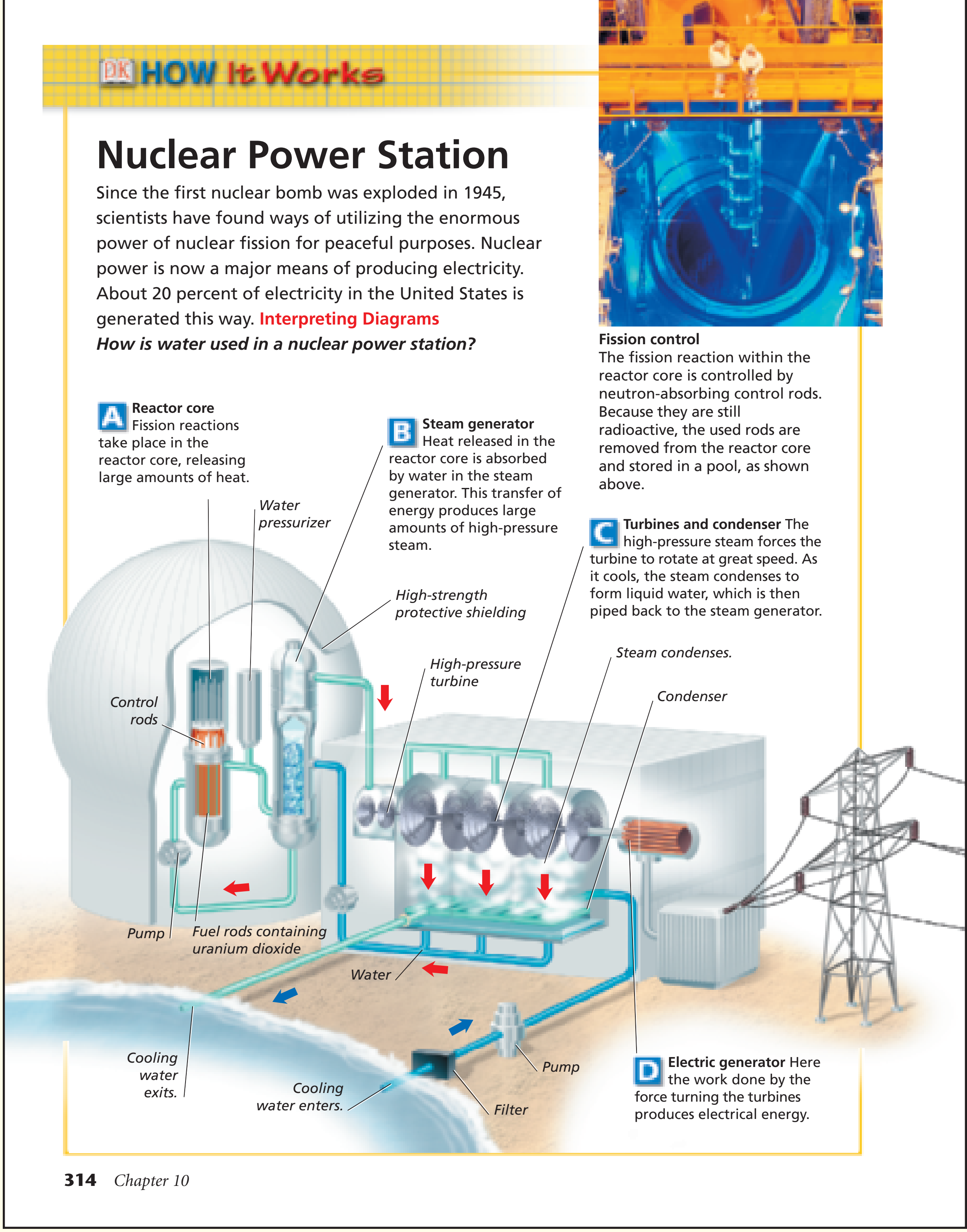
A bundle of fuel rods contains slightly more than the critical mass of uranium-235. Control rods are placed in the bundle in order to control when and how quickly the process of fission occurs.

Interpreting Diagrams In a nuclear power station, water is used to transfer the energy generated in the reactor core. Heat released in the core is absorbed by water in the steam generator. The steam produced is used to drive a turbine; the kinetic energy of the turbine is then converted into electrical energy. Water is also used as a coolant to condense the steam exiting the turbine. The steam condenses into liquid water and is piped back to the steam generator.
Visual

For Enrichment

L3

The U.S. Navy uses nuclear reactors to power many different types of ships, ranging from submarines to aircraft carriers. Nuclear power is useful on ships that are at sea for long periods of time because the ships do not have to carry large quantities of fuel or refuel while they are on a mission. Ask students to research how nuclear reactors in ships differ from those in nuclear power stations.
Verbal



HOW It Works

Nuclear Power Station

Since the first nuclear bomb was exploded in 1945, scientists have found ways of utilizing the enormous power of nuclear fission for peaceful purposes. Nuclear power is now a major means of producing electricity. About 20 percent of electricity in the United States is generated this way. **Interpreting Diagrams** ***How is water used in a nuclear power station?***

Fission control The fission reaction within the reactor core is controlled by neutron-absorbing control rods. Because they are still radioactive, the used rods are removed from the reactor core and stored in a pool, as shown above.

A **Reactor core** Fission reactions take place in the reactor core, releasing large amounts of heat.

B **Steam generator** Heat released in the reactor core is absorbed by water in the steam generator. This transfer of energy produces large amounts of high-pressure steam.

C **Turbines and condenser** The high-pressure steam forces the turbine to rotate at great speed. As it cools, the steam condenses to form liquid water, which is then piped back to the steam generator.

D **Electric generator** Here the work done by the force turning the turbines produces electrical energy.

Fusion

Another type of nuclear reaction that can release huge amounts of energy is fusion. **Fusion** is a process in which the nuclei of two atoms combine to form a larger nucleus. As in fission, during fusion, a small fraction of the reactant mass is converted into energy.

On any day or night, you can detect the energy released by fusion reactions occurring far away from Earth. The sun and other stars are powered by the fusion of hydrogen into helium. Inside the sun, an estimated 600 million tons of hydrogen undergo fusion each second. About 4 million tons of this matter is converted into energy.

Matter within the sun and other stars exists as plasma. **Plasma** is a state of matter in which atoms have been stripped of their electrons. You can think of plasma as a gas containing two kinds of particles—nuclei and electrons. Although fusion occurs at millions of degrees Celsius, plasma can exist at much lower temperatures. Scientists estimate that more than 99 percent of matter in the universe is plasma.

Fusion may someday provide an efficient and clean source of electricity. Scientists envision fusion reactors fueled by two hydrogen isotopes, deuterium (hydrogen-2) and tritium (hydrogen-3). The fusion of deuterium and tritium produces helium, neutrons, and energy.

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n} + \text{energy}$$

Scientists face two main problems in designing a fusion reactor. They need to achieve the high temperatures required to start the reaction, and they must contain the plasma.

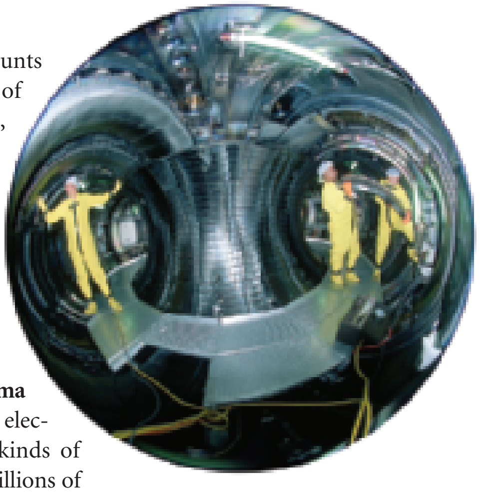


Figure 21 The Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory in Princeton, New Jersey, was one of the very few fusion reactors that have been built. It was retired in 1997, after 15 years of experimentation.

Section 10.4 Assessment

Reviewing Concepts

1. Under what conditions does the strong nuclear force overcome the repulsive effect of electric forces in the nucleus?
2. What property of fission makes it a useful reaction?
3. What particles are affected by strong nuclear forces?
4. What must happen in order for a nuclear chain reaction to occur?
5. Why is a cooling system necessary in a nuclear reactor?
6. How do the products of a fusion reaction differ from the products of a fission reaction?

Critical Thinking

7. **Inferring** How does the strong nuclear force affect an atom's electrons? (*Hint:* Think about where the electrons are located in the atom.)
8. **Inferring** Why do fission chain reactions of uranium-235 not occur in underground uranium deposits?

Connecting Concepts

Fossil Fuels Reread the description of fossil fuels in Section 9.1. Then compare fossil fuel combustion with nuclear fission.

Fusion

Address Misconceptions

L2

Students may think that the sun is actually burning because it gives off light and heat. Explain that the light and heat given off by the sun result from nuclear fusion, not combustion.
Verbal

Build Science Skills

L2

Observing Tell students that the sun produces energy by nuclear fusion. Explain that fusion releases very large amounts of energy. Ask, **How do you know that the sun produces large amounts of energy?** *(Students may come up with examples such as, heat, bright sunlight, sunburn, and so on.)*
Logical

3 ASSESS

Evaluate Understanding

L2

Have students write down three characteristics of nuclear fission and fusion. Have students take turns giving a characteristic while the other students identify whether it is typical of fission or fusion.

Reteach

L1

Use Figures 18 and 19 to summarize controlled and uncontrolled fission reactions.

Connecting Concepts

Possible answer: Both fossil fuel combustion and nuclear fission produce heat, which can be used to generate electricity. Fossil fuel combustion is a chemical reaction, the products of which include carbon dioxide, water, carbon monoxide, nitrogen oxides, and soot. Air pollution is one of the main drawbacks of fossil fuel combustion as an energy source. Fission is a nuclear reaction whose products include lighter nuclei and neutrons. Radioactive waste is one of the main drawbacks of fission as an energy source.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 10.4.

Section 10.4 Assessment

1. Over very short distances, strong nuclear forces are much greater than the electric forces in the nucleus.
2. Tremendous amounts of energy can be produced from very small amounts of mass.
3. Strong nuclear forces act among protons, among neutrons, and among protons and neutrons.
4. Each nucleus that splits must on average produce at least one neutron that results in the fission of another nucleus.
5. A cooling system is necessary in a nuclear reactor to prevent the reactor core from overheating.
6. The products of fusion are less massive nuclei such as helium. The products of fission are more massive nuclei, such as barium or krypton.
7. The strong nuclear force has no effect on an atom's electrons because it acts only over very short distances within the nucleus.
8. Natural deposits of uranium-235 generally do not occur in amounts great enough to reach a critical mass.