Fission and Fusion

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CHAPTER 1 Fission and Fusion

Lesson Objectives

- Define nuclear fission and nuclear fusion.
- Write fission reactions and identify the components of these reactions.
- Describe the fission reactions employed in nuclear power plants.
- Write examples of nuclear fusion reactions.
- List the difficulties associated with using fusion reactions to generate power.

Lesson Vocabulary

- **nuclear fission**: The process of bombarding heavy nuclei with neutrons, causing them to split into two smaller nuclei.
- **nuclear reactor**: A technology used in nuclear power plants to facilitate fission chain reactions in order to vaporize steam, which then powers turbines and generates electricity.
- **nuclear fusion**: The process of combining small nuclei into larger nuclei, creating large amounts of energy.

Check Your Understanding

- What are the various types of spontaneous nuclear decay?

Nuclear Fission

Radioactive decay, such as the emission of alpha or beta particles, is not the only way that nuclei can be transformed into other isotopes. As it turns out, bombarding certain heavy nuclei with neutrons will cause them to split into two smaller nuclei, in a process known as **nuclear fission**. Nuclear fission was first discovered by the German scientists Fritz Strassman and Otto Hahn in the 1930s. They began their work by bombarding atoms of uranium with neutrons, hoping to create other large elements. Instead, they were surprised to find barium-141, a much smaller element. Later on in collaboration with Austrian physicist Lise Meitner, they demonstrated the release of neutrons and a large amount of energy along with the smaller nuclei.

Figure 1.1 illustrates the basic nuclear fission process. A neutron (generally produced by some controlled process, not usually a natural event) collides with an atom of uranium-235. Then, a very unstable U-236 atom forms, which proceeds to split into two smaller nuclei (Kr-92 and Ba-141). This process also results in the release of three new neutrons and a large amount of energy.

In **Figure** 1.2, we see the possible fates of the newly generated neutrons. Some will be lost to the surroundings, and others will collide with non-fissionable nuclei, such as uranium-238. However, some will collide with other U-235 atoms, thus propagating the fission process and releasing even more neutrons. We will see later how this propagation of neutrons can be employed in a nuclear reactor to generate electricity.

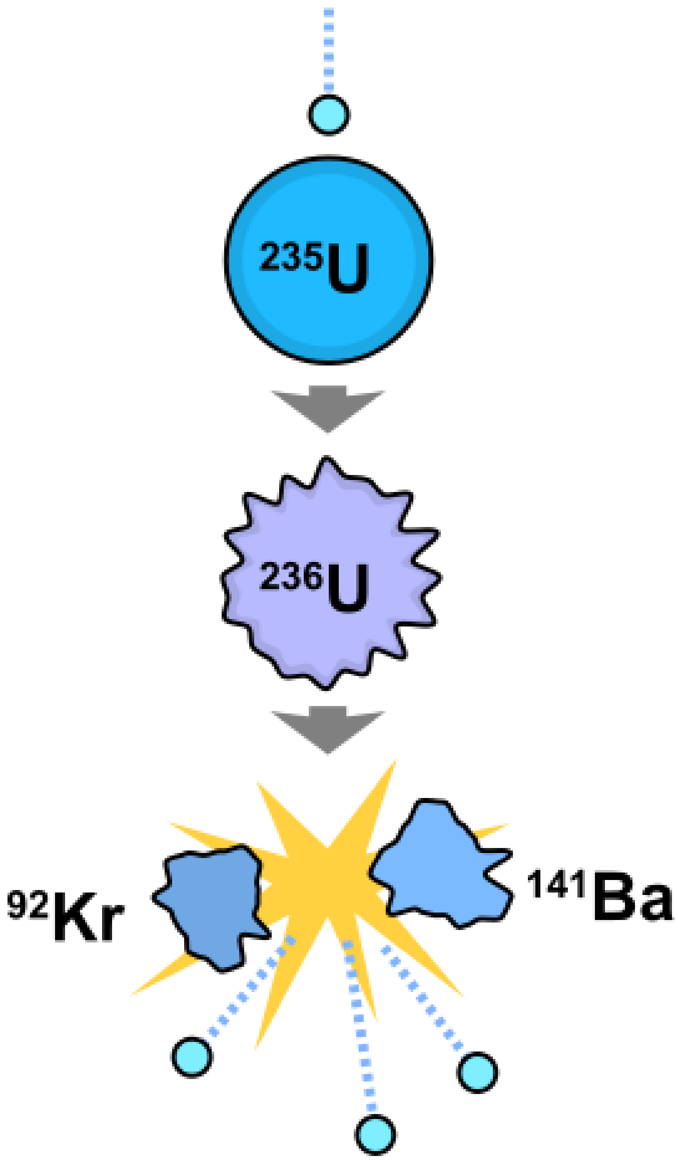

FIGURE 1.1
The products of a nuclear fission reaction include smaller nuclei, neutrons, and energy.

As with the equations for nuclear decay, fission reactions are balanced in terms of both mass number and atomic number. For example, the fission process illustrated in the **Figure** 1.2 is represented by the following equation:

$^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow ^{92}_{36}\text{Kr} + ^{141}_{56}\text{Ba} + 3^{1}_{0}n + \text{energy}$

On each side of the equation, the mass numbers add up to 236 and the atomic numbers add up to 92. Another set of possible fission products from U-235 is formed by the following nuclear reaction:

$^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow ^{87}_{35}\text{Br} + ^{146}_{57}\text{La} + 3^{1}_{0}n + \text{energy}$

Again both the mass numbers and the atomic numbers are balanced on each side of the equation.

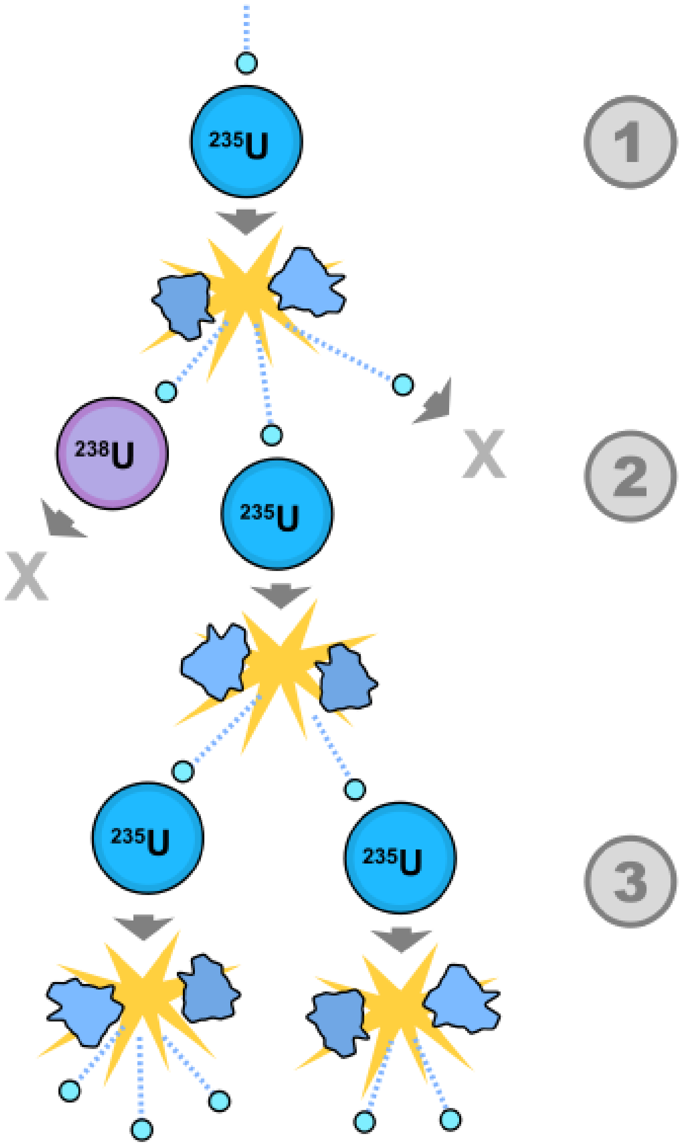

FIGURE 1.2
Nuclear fission can be thought of as a chain reaction.

Nuclear Power Generation

The generation of electricity is critical for the operation of nearly all aspects of modern society. The following diagram illustrates the types of fuels used to generate electrical power in the Unites States. In 2009, almost 45% of the power generated in the U.S. was derived from coal, with natural gas making up another 23% of the total. The third primary source of electrical energy is nuclear power, which accounts for approximately 20% of the total amount generated. All of these fuels give off energy in the form of heat. This heat is used to convert water into steam, which is then used to turn a turbine, thus generating electrical power.

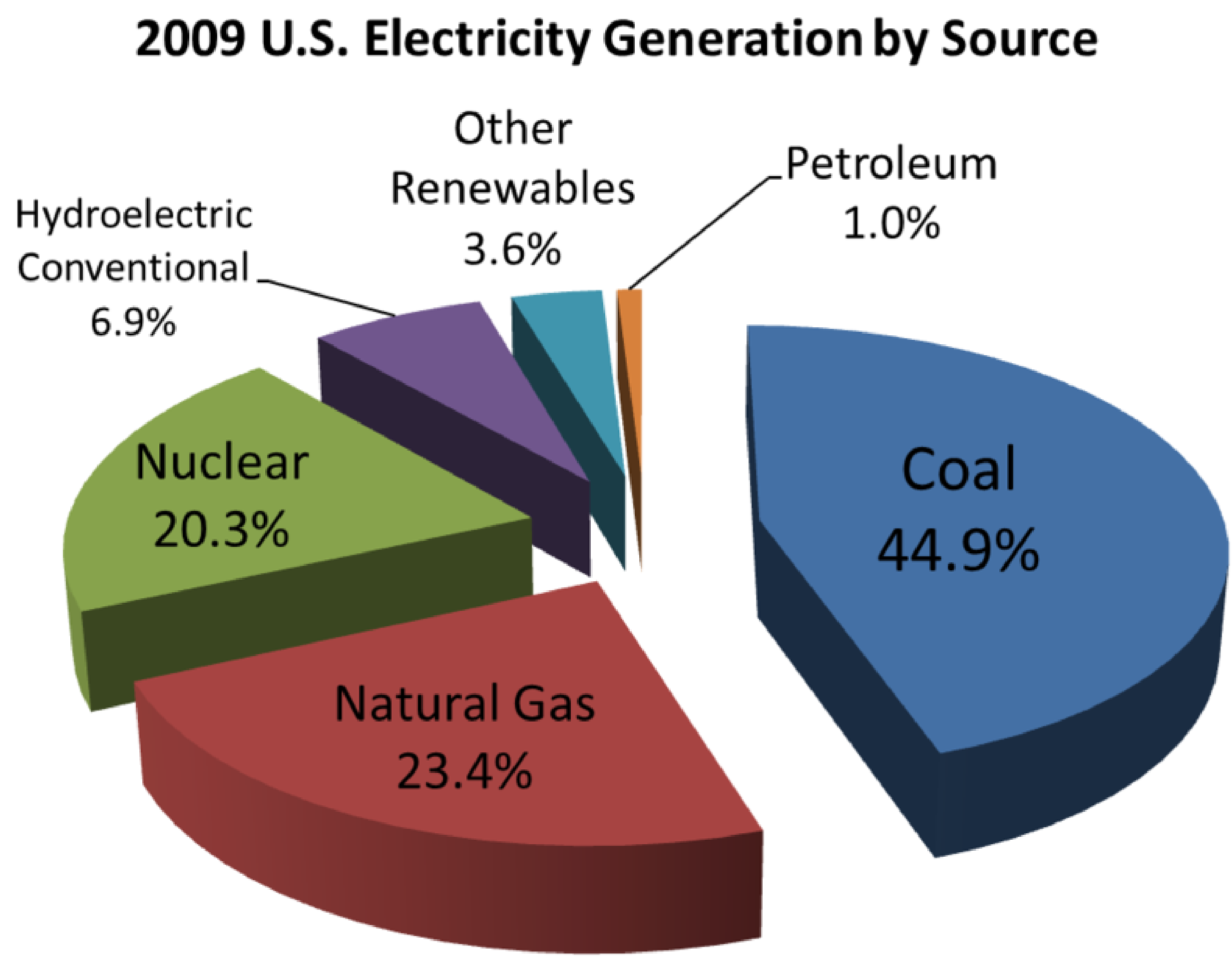

FIGURE 1.3

Electricity is one of the main sources of energy used to generate power and is derived from many processes.

Figure 1.4 shows the layout of a typical nuclear power plant which employs **nuclear reactors** to generate energy. The radioactive rods are in the red container, where the energy released during the fission process is used to vaporize water into steam. The steam passes through the turbine and causes the turbine to spin, generating electricity. As the steam condenses, it is run through a cooling tower to lower its temperature. The water then recirculates through the reactor core to be used again.

The control rods, generally made of boron or various metal alloys, play an important role in the modulation of the nuclear chain reaction. Each fission event produces more neutrons than were present initially. If each neutron caused the fission of another atom of U-235, this chain reaction would accelerate, resulting in more and more energy and neutrons being released. The purpose of the control rods is to absorb excess neutrons, which regulates the rate of the chain reaction and prevents overheating. If enough energy were released all at once, a nuclear meltdown might occur, in which the radioactive material starts to melt and leak out of the reactor core along with the water. Control rods help to prevent this type of situation.

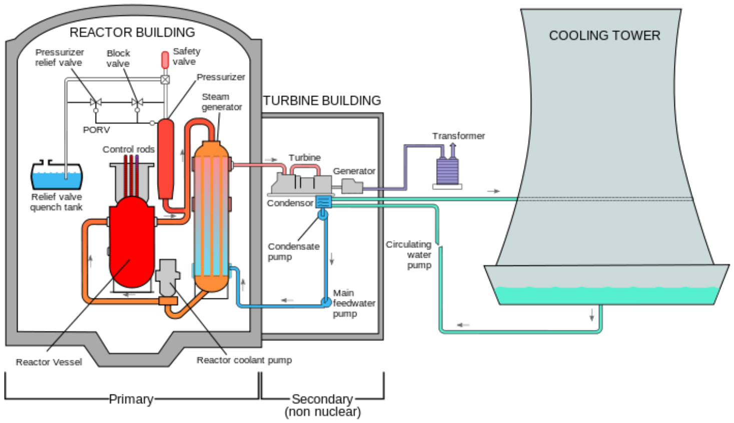

FIGURE 1.4

Nuclear Fusion

In contrast to nuclear fission, in which smaller nuclei are created from a larger nucleus, **nuclear fusion** combines smaller nuclei into larger ones. If the starting nuclei are very small, this process releases an extremely large amount of energy. The fusion of hydrogen atoms into helium is responsible for the energy released by the Sun and other small stars. A typical fusion reaction is shown in the following figure:

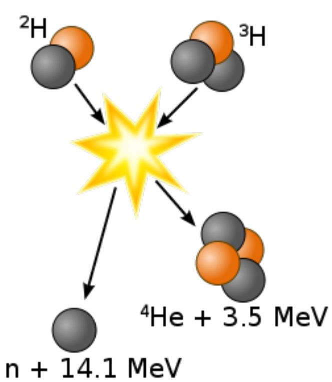

FIGURE 1.5
Collisions between hydrogen atoms demonstrate one form of nuclear fusion.

In this reaction, two different isotopes of hydrogen collide to form a helium-4 nucleus, which is much more stable. A neutron is also ejected, along with the release of large amounts of energy often in the form of gamma rays. Hydrogen-2 (deuterium) and hydrogen-3 (tritium) can be formed by other fusion reactions between isolated protons and neutrons. All of these particles are plentiful in the extremely high temperatures present inside a star.

Larger stars are also fueled by fusion reactions involving heavier nuclei, such as carbon, nitrogen, and oxygen. However, the principle is the same; smaller nuclei collide and fuse into a larger nucleus, resulting in the release of energy.

Because so much energy is released during nuclear fusion, being able to reproduce this process in a controlled fashion would provide almost limitless amounts of energy. Additionally, the waste products from fusion reactions are generally not radioactive, so this would be a much less hazardous source of nuclear energy than fission reactors.

Unfortunately, nuclear fusion reactions generally require temperatures in the millions of degrees, which is very difficult to achieve in the laboratory. The development of other methods to force atoms close enough together to cause a reaction have been limited, and harnessing the energy released by nuclear fusion reactions is not yet a feasible option.

Lesson Summary

- Nuclear fission reactions are initiated when certain heavy nuclei, such as uranium-235, collide with free neutrons. The products of a fission reaction are two smaller isotopes, more neutrons, and a great deal of energy.
- Nuclear reactors use fission reactions to vaporize water. The resulting steam is used to drive a turbine, which generates electricity.
- Nuclear fusion involves the collision of smaller atoms to form larger ones. Extremely large amounts of energy are released in this process.
- Nuclear fusion reactions occur in stars but are difficult to reproduce in a controlled laboratory setting, due to the extreme temperatures required.

Lesson Review Questions

1. Define nuclear fission.
2. What happens to newly generated neutrons in nuclear fission reactions?
3. Write two different fission reactions involving U-235.
4. Explain how radioactive isotopes can be used to generate electricity.
5. Define nuclear fusion.
6. Describe the problems associated with the development of nuclear fusion as a feasible power source.

Further Reading/Supplementary Links

- Animation of nuclear fission process: http://upload.wikimedia.org/wikipedia/commons/8/86/UFission.gif
- Fusion reactions in the sun: http://zebu.uoregon.edu/~soper/Sun/fusionsteps.html
- Nuclear reactions in the sun: http://www.cartage.org.lb/en/themes/sciences/chemistry/nuclearchemistry/NuclearReactions/NuclearFusion/NuclearFusion.htm
- Comparison between fission and fusion reactions: http://www.diffen.com/difference/Nuclear_Fission_vs_-Nuclear_Fusion

Points to Consider

- Do radioisotopes have any constructive uses other than energy production?

References

1. User:Fastfission/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Nuclear_fission.svg . Public Domain
2. User:Fastfission/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Fission_chain_reaction.svg . Public Domain
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