

Unit 11: Nuclear Energy

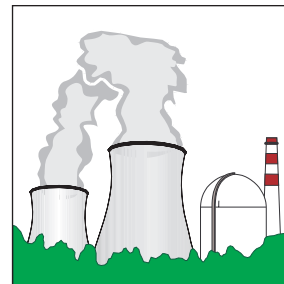
This unit explains that atoms store huge amounts of energy. Students will learn about fission and fusion and also gain knowledge about the nature of nuclear changes and their impact on living things.

Student Goals

- Develop an understanding of the nature, properties, types, and uses of nuclear radiations.
- Describe how nuclear fission and fusion may be used for energy.
- Define chain reaction, nuclear reactor, and control rod, and describe their interaction in nuclear power plants.
- State positive and negative reasons concerning the continued development of the nuclear fission reactor.
- Define radioactivity.
- Understand the process by which scientific ideas are conceived and developed.

Unit Focus

- Know that a number of elements have heavier, unstable nuclei that decay, spontaneously giving off small particles and waves that result in a small loss of mass and release a large amount of energy. (SC.A.2.4.3)
- Know that nuclear energy is released when small, light atoms are fused into heavier ones. (SC.A.2.4.4)
- Understand that there is conservation of mass and energy when matter is transformed. (SC.B.1.4.2)



- Know that the forces that hold the nucleus of an atom together are much stronger than electromagnetic force and that this is the reason for the great amount of energy released from the nuclear reactions in the sun and other stars. (SC.C.2.4.4)



Vocabulary

Use the vocabulary words and definitions below as a reference for this unit.

- atom** the smallest unit of an element that is still that element; the basic building block of matter
- chain reaction** a self-sustaining nuclear reaction; it continues without the addition of outside energies
- chemical energy** the energy that is stored in chemicals
- control rod** a barrier that slows a nuclear reaction by absorbing excess radiation
- electromagnetic energy** the energy that results from the interaction of the electric and magnetic fields
- electromagnetic force** the forces of attraction and repulsion between charged particles, resulting in electricity and magnetism
- electron** the negatively charged particle of an atom; the electron moves around the center of the atom (nucleus)
- energy** the ability to do work or cause change
- fission** splitting the nucleus of an atom into two lighter parts



- fission reactor** a type of nuclear reactor that splits the nuclei of atoms
- fusion** a nuclear reaction in which two or more nuclei are pushed together to form one large nucleus
- fusion reactor** a type of nuclear reactor that would combine atoms
- gravity** the attraction of matter toward another body of matter
Example: Earth's gravity holds us on its surface.
- half-life** □ the time it takes one-half of the atoms of a radioactive sample to decay
- isotope** an atom or group of atoms with the same atomic number but different atomic mass than other atoms of a specific element; this difference in mass is based on a difference in the number of neutrons within the nucleus of the atom
- law of conservation of energy** the law that energy cannot be created or destroyed, only changed from one form to another during a physical or chemical change
- law of conservation of mass** the law that matter cannot be created or destroyed, only changed from one form to another during a physical or chemical change



- mass** the amount of matter in a substance
- matter** anything that has both mass and volume
- mechanical energy** the energy of moving things
- neutron** the neutral particle found in the nucleus of an atom; a neutron has no charge
- nuclear energy** the energy that holds the nuclei of atoms together; it is released in nuclear reactions and may be used to produce heat, electricity, or other forms of energy
- nuclear reaction** a reaction that occurs when an atom is split; large amounts of energy are released
- nuclear reactor** a machine used to control or create a nuclear chain reaction
- nucleus** the center region of the atom around which the electron(s) move; plural: nuclei
- proton** the positively charged particle in the nucleus of an atom
- radiation** the movement of energy as a wave
- radioactive** describing those elements or isotopes that spontaneously decompose and give off radiation



radioactive waste the waste produced by a nuclear reactor; though unusable it still releases radiation

radioactivity forms of energy given off by nuclear material

theory of relativity the theory that there is a fundamental relationship between matter and energy; $E=mc^2$ (E stands for energy, m stands for mass, and c stands for the speed of light.)



Introduction

There are many forms of **energy** in the world. As you learned in the last unit, many of these are derived from the forces of electromagnetism.

Gasoline that burns, muscles that contract, and **electrons** that flow are all the result of this **electromagnetic force**. Although we use this force constantly, it is relatively weak when compared to nuclear forces. Just as with *electromagnetic forces*, nuclear forces produce *energy*. The sun is the ultimate source of almost all our energy. The energy of the sun comes from **nuclear energy**.



The sun is the ultimate source of almost all our energy.

Nuclear energy involves the nuclei (plural of nucleus) of **atoms**. Subatomic particles in the **nucleus** of *atoms* are called **neutrons** and **protons**. These particles are **matter**. In Unit 5: Chemical Formulas and Equations, you learned that *matter* cannot be created nor destroyed. What about energy? Energy can change form, but can never be destroyed. This is called the **law of conservation of energy**. (This concept is covered in Unit 9: Forms of Energy). This law applies to the energy you use every day.

Electromagnetic forces provide us with most of the energy we use on a daily basis. Most of this energy has originated in sunlight. For example, sunlight is used by plants. Corn plants store this energy as **chemical energy**. The *chemical energy* comes to you as food. You use the chemical energy for many purposes. You will produce heat, may make sound, or use **mechanical energy**. The energy you use, though, originated in the sun's light. This unit discusses how **nuclear reactions** only appear to break the **law of conservation of mass** and the *law of conservation of energy* and how the result is all the energy you use.

What Is Nuclear Energy?

Most of the **electromagnetic energy** we know comes from the outer portions of atoms, the *electrons*. Within the center of the atom, however, is the *nucleus*. The energy that holds tightly together the nucleus of atoms is



nuclear energy. Compared to the electromagnetic forces of the atom, the nuclear energy is immense. By releasing some of this energy, the sun creates light. The sun's light gives us energy that runs the world.

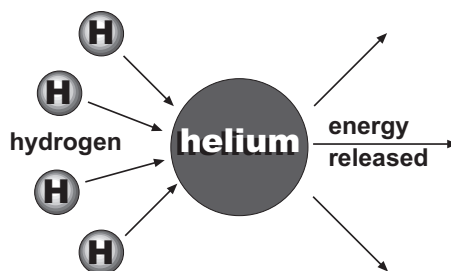
Most of the energy sources we use today are derived from sunlight. Oil and natural gas, and even wood for fires, are the products of sunlight. Unfortunately, this is not a very efficient way to use the sun's energy. Much of the energy of the sun is lost as heat. Because the world's population grows every day, we find that we need more and more energy. Nuclear energy may be one way of providing that energy. With the use of nuclear energy also comes the serious risk of the escape of harmful radiation, such as in the disaster in 1986 at a nuclear power plant in Chernobyl, in the Ukraine. Many safeguards must be taken to prevent accidents.



The sun's light gives us energy that runs the world.

How Does the Sun Work?

There are two main ways to release nuclear energy. The sun uses a process known as **fusion**. The sun is made of light gases being held together by **gravity**. Most of this gas is the lightest of elements, hydrogen. In the center of the sun, the hydrogen gas is being pushed together by *gravity*. This pressure is incredibly high. Because of this pressure, there is also a large amount of heat. Under the pressure and heat, the hydrogen changes. Four hydrogen atoms will combine to form one helium atom. When this happens, energy is released.



4 hydrogen atoms combine to form 1 helium atom - energy released

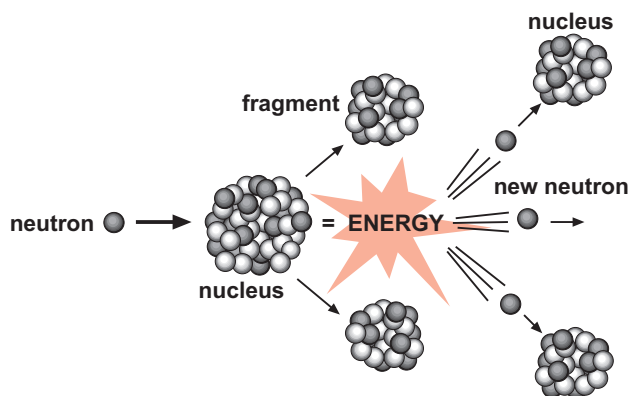


You should remember that the law of conservation of energy says energy can neither be created nor destroyed. From where did the energy come? When the four hydrogen atoms were changed into one helium atom, a small part of their **mass** was lost. Compare the *mass* of four hydrogen atoms to one helium atom. The hydrogen atoms have a mass of 4.03188. The mass of the helium is 4.0026. In this case, it looks like we lost a mass of 0.02928. What has actually happened is that this mass has been changed to nuclear energy. The mass was not destroyed, and the energy was not created. They were just changed. The small amount of mass becomes the large amount of energy that comes from the sun.

The process of taking these lighter elements and making a heavier element is called *fusion*. Fusion powers the sun and releases large amounts of energy. Because of the heat and pressure needed, however, scientists have not been able to control fusion. So far, the only use of fusion by humans has been to create highly destructive weapons. No one knows if we will ever find a peaceful use for fusion.

What Is Fission?

In the previous section, you learned about one way to release nuclear energy, fusion. This section will examine another way of releasing nuclear energy, **fission**. *Fission* occurs when the nucleus of an atom splits and releases some of its nuclear energy. To understand how and why this happens, we need to look at the nucleus of atoms.

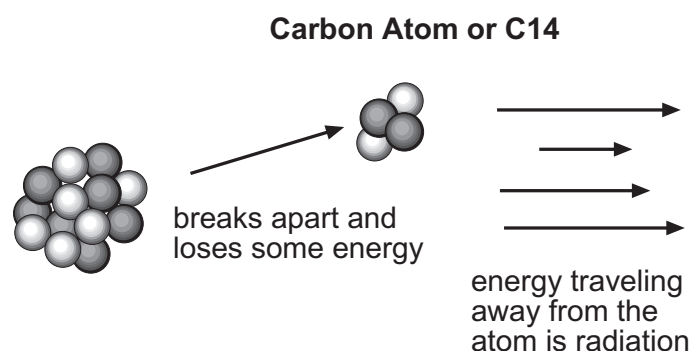


Fission occurs when the nucleus of an atom splits and releases some of its nuclear energy.

Remember that the nucleus is made of *neutrons* and *protons*. In any given element, the number of protons in a nucleus never changes. This is not



true of the number of neutrons. Consider carbon. Most atoms of carbon have six neutrons as well as six protons. This will give the nucleus a mass of 12. Because the chemical symbol of carbon is C, then this type of atom is called C12. Some carbon atoms, however, may have seven neutrons. The nucleus of such an atom would have a mass of 13 and is called C13. The element is still carbon, but the atom is a little heavier. Other than that, the atom behaves just like an atom with six neutrons, C12. However, if we add another neutron, for a total of eight, the atom will behave differently. This atom will have a nucleus with a mass of 14, but it will still be carbon. It is known as C14. How is C14 different? If left by itself, the nucleus will break apart and lose some energy. The energy will travel away from the atom in the form of a wave, and we know this as **radiation**. *Radiation* is any form of energy that travels in a wave. Nuclear radiation, however, is sometimes dangerous because it has such high energy.



You may be wondering if there is a special name for atoms with a different number of neutrons. The name for these are **isotopes**. We discussed three *isotopes* of carbon. Most isotopes of atoms are harmless. Some are **radioactive**. That is, some isotopes, like the C14 isotope, spontaneously produce radiation. *Radioactive* material has nuclei that break down and release energy and neutrons. The element uranium is naturally radioactive and constantly releases energy and radioactive particles. These radioactive particles are made from the protons, neutrons, and electrons of the atom.

Where do the particles go? The particles travel outward. When the uranium nucleus is hit with a particle, it becomes unstable. Eventually it will split in two. Splitting an atom is called fission. When the atoms split they lose a small amount of matter that is changed into a large amount of



energy. Not all elements have atoms that can be split. When the uranium atom splits, it throws out more radioactive particles. These particles will split other atoms. This will continue to happen. This reaction is called a **chain reaction**. Besides uranium, there are many other elements that spontaneously produce radiation. These include plutonium, radium, and cesium.



Practice

Circle the letter of the correct answer.

1. The sun's light gives us _____ that runs the world.
 - a. energy
 - b. fission
 - c. isotopes
2. Gasoline that burns, muscles that contract, and electrons that flow are all the result of this _____ .
 - a. control force
 - b. radiation
 - c. electromagnetic force
3. The energy of the sun comes from _____ .
 - a. nuclear energy
 - b. sunshine
 - c. a chain reaction
4. Nuclear energy involves the nuclei of _____ .
 - a. a fusion reactor
 - b. atoms
 - c. radioactive waste
5. Subatomic particles in the _____ of *atoms* are called *neutrons* and *protons*.
 - a. fusion
 - b. nucleus
 - c. control rod
6. Most of the _____ we know about comes from the outer portions of atoms, the electrons.
 - a. electromagnetic energy
 - b. theory of relativity
 - c. electron core level



7. A nuclear reaction in which two or more nuclei are pushed together to form one large nucleus is known as _____ .
 - a. fission reactor
 - b. nuclear waste
 - c. fusion

8. The energy will travel away from the atom in the form of a wave. We call this traveling energy _____ .
 - a. radiation
 - b. fusion
 - c. run-away energy

9. A special name for atoms with a different number of neutrons is called _____ .
 - a. atomites
 - b. isotopes
 - c. chain reactions

10. _____ material has nuclei that break down and release energy and neutrons.
 - a. Radioactive
 - b. Relativity
 - c. Nuclear

11. When a uranium atom splits, it throws out more radioactive particles. These particles will split other atoms. This reaction, which will continue to happen, is called a _____ .
 - a. split atom reaction
 - b. radioactive reaction
 - c. chain reaction

12. _____ occurs when the nucleus of an atom splits into two lighter parts and releases some of its nuclear energy.
 - a. Radioactive
 - b. Fission
 - c. Computer



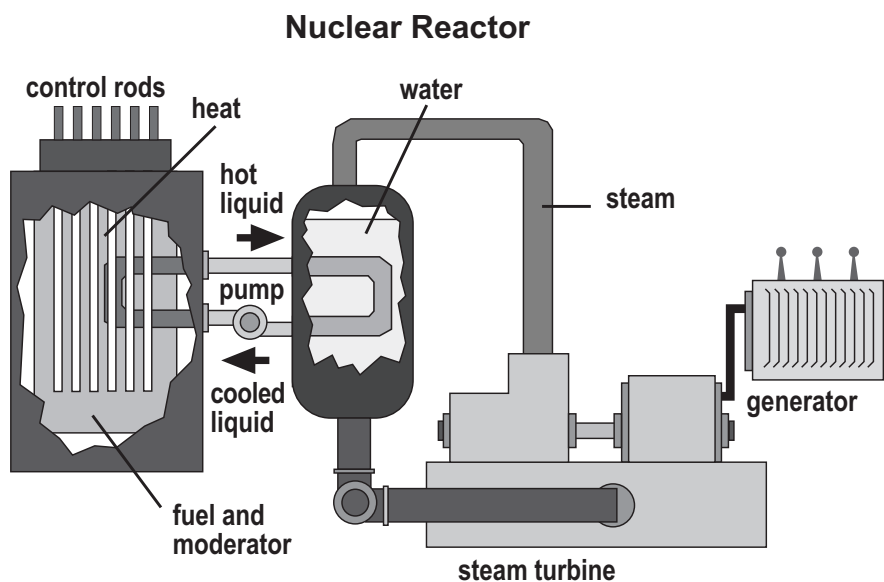
13. A _____ is a reaction that occurs when an atom is split and large amounts of energy are released.
- proton reaction
 - nuclear reaction
 - relativity reaction
14. Not all elements have _____ that can be split.
- radioactive waste
 - control rods
 - atoms



Controlling Nuclear Reactions

Large amounts of energy are released by fission and fusion reactions. Why can't this energy be used to run generators? It can, but first it must be controlled. After learning how to use nuclear energy to destroy, scientists found ways to control it.

Fission can be controlled. It must take place slowly, but at a steady speed. In this way, fission can be used to produce useful energy. A **nuclear reactor** is used to control a nuclear *chain reaction*. All nuclear reactors are **fission reactors**. These use uranium atoms for fuel. They are hit with neutrons. When the reaction begins, a **control rod** is used. A *control rod* is made of a substance that absorbs neutrons. Control rods can be used to slow down fission reactions. By absorbing some of the neutrons, the chain reaction does not become explosive. If the reaction must be speeded up, the rods are removed.



A *nuclear reactor* produces heat. This heat can be used to run generators. It takes a very small amount of nuclear fuel to produce large amounts of energy. Is this the answer to man's energy needs? There are nuclear power plants being used today. Unfortunately, nuclear fission creates some problems. **Radioactive waste** is one of these problems.



Radioactive Material

Radioactive wastes are no longer useful as fuel, but they are still radioactive. **Radioactivity** can damage or kill living cells. Large doses of radiation can cause severe burns. On the other hand, radiation can be helpful. It can be used to kill cancer cells. Low levels of radiation can be used to find tumors in people, decay in teeth, and breaks in bones.

Think about the *nuclear reactor*. It uses uranium for fuel. Uranium is radioactive. A nuclear reactor produces waste that is radioactive. This radioactive waste is harmful to living things. What happens to this waste? It cannot be destroyed. Some radioactive material may require millions of years to decay. A measure of time required for substances to decay is called **half-life**. The *half-life* is the amount of time it takes for half of the atoms in the radioactive substance to decay. Some of the radioactive waste is stored in underground tanks. Some is sunk deep in the ocean. People worry that these methods of disposal might leak.

Fusion reactors would not produce radioactive waste. Remember that fusion needs high temperatures. Scientists have not yet figured out how to produce and control these high temperatures. It is hoped that in the future, man may be able to solve some of the problems of nuclear energy.

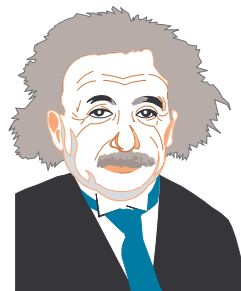
Albert Einstein and Nuclear Power

Albert Einstein was a physicist who lived from 1879 to 1936. He created the theory that stated mass and energy were related. His theory stated that the energy of matter was equivalent to the mass of the object multiplied by the square of the speed of light. This equation is written as follows:

$$E=mc^2$$

E represents energy. The *m* stands for mass. The speed of light is represented by a *c*. This theory led to many outcomes.

When Einstein first conceived of this theory, it was not seen as a formula for making energy. At first, there was resistance to the concept. Had the theory not shown itself to be accurate, it would surely have been rejected. Yet, the **theory of relativity** was not rejected. Despite this, it took decades



Albert Einstein was a physicist.



before the theory could be applied. Its first application was in the creation of atomic bombs. Many other scientists had to add theories and knowledge. Sometimes such knowledge is expected. At other times, it is unexpected.

Again, the application of the theory for bombs was not what Einstein had envisioned. He simply developed a theory. The development of bombs and nuclear reactors and an understanding of the sun were not necessarily expected. Although Albert Einstein made these things possible, he did not have them in mind when working on the theory of relativity.

Summary

Atoms store huge amounts of energy. This energy can be released by fission or fusion. Fusion is the combining of light elements into heavier elements. The sun uses fusion. Fission is the splitting of atoms. Nuclear reactors control the speed of fission reactions. Nuclear power plants produce energy and dangerous radioactive waste. Scientists are searching for ways to eliminate the problems of using nuclear energy. As Einstein's theory of relativity demonstrates, ideas in science are limited by the purpose for which they are conceived, are sometime rejected, may grow from unexpected discoveries, and often grow slowly from many contributors.



Practice

Use the list below to write the correct term for each definition on the line provided.

control rod	nuclear reactor	radioactivity
fission reactor	radioactive waste	theory of relativity
fusion reactor		

- _____ 1. a type of nuclear reactor that would combine atoms
- _____ 2. a barrier that slows a nuclear reaction by absorbing excess radiation
- _____ 3. the theory that there is a fundamental relationship between matter and energy; $E=mc^2$ (E stands for energy, m stands for mass, and c stands for the speed of light.)
- _____ 4. the waste produced by a nuclear reactor; though unusable it still releases radiation
- _____ 5. a type of nuclear reactor that splits the nuclei of atoms
- _____ 6. a machine used to control or create a nuclear chain reaction
- _____ 7. forms of energy given off by nuclear material



Lab Activity: Chain Reactions

Facts:

- Chain reactions can be controlled or uncontrolled

Investigate:

- You will demonstrate that chain reactions can be blocked.

Materials:

- set of dominoes or domino-like chips
- chalkboard eraser

1. Stand 10 to 20 dominoes on one end, one behind the other. (Leave about $\frac{1}{2}$ inch between each one.)
2. Push the first one down.
 - a. What happens to the rest? _____
 - b. Was this reaction controlled or uncontrolled? _____
3. Line the dominoes up again. Place a chalkboard eraser after the 5th or 6th domino. Continue to line up the rest of the dominoes.
4. Push the first domino.
 - a. Did all the dominoes fall? _____
 - b. What stopped the dominoes? _____
 - c. What controlled the reaction? _____
 - d. What part of a nuclear reactor is represented by the eraser?





Practice

Write **True** if the statement is correct. Write **False** if the statement is not correct.

- _____ 1. *Nuclei* is the plural of *nucleus*.
- _____ 2. Very small amounts of energy are released by fission and fusion.
- _____ 3. The first atomic bomb was a fission reaction.
- _____ 4. Fission can be controlled using a nuclear reactor and can be used to produce useful energy.
- _____ 5. A nuclear reactor cannot produce heat.
- _____ 6. Nuclear power plants produce energy.
- _____ 7. Nuclear fission creates radioactive wastes.
- _____ 8. Radioactivity can damage or kill living cells.
- _____ 9. All isotopes of carbon have the same number of neutrons.
- _____ 10. Since radioactive waste cannot be destroyed, it must be stored.

