Understanding the Atom

Protons, Neutrons, and Electrons—How Atoms Differ

Before You Read

What do you think? Read the three statements below and decide whether you agree or disagree with them. Place an A in the Before column if you agree with the statement or a D if you disagree. After you've read this lesson, reread the statements to see if you have changed your mind.

Before	Statement	After
	4. All atoms of the same element have the same number of protons.	
	5. Atoms of one element cannot be changed into atoms of another element.	
	6. Ions form when atoms lose or gain electrons.	

Read to Learn

The Parts of the Atom

Inside an atom is a very tiny nucleus surrounded by empty space. Positively charged protons and neutral neutrons are inside the nucleus. Negatively charged electrons whiz by in the empty space around the nucleus.

The table below compares the properties of protons, neutrons, and electrons. Protons and neutrons have about the same mass. Electrons have a much smaller mass than protons or neutrons. As a result, the nucleus contains most of an atom's mass. All atoms contain protons, neutrons, and electrons. However, different types of atoms have different numbers of these particles.

Properties of Protons, Neutrons, and Electrons

	Electron	Proton	Neutron
Symbol	e–	p	n
Charge	1–	1+	0
Location	electron cloud around nucleus	nucleus	nucleus
Relative mass	1/1,840	1	1

Key Concepts

- What happens during nuclear decay?
- How does a neutral atom change when its number of protons, electrons, or neutrons changes?

Mark the Text

Building Vocabulary As you read, circle all the words you do not understand. Highlight the part of the text that helps you understand these words. Review the marked words and their definitions after you finish reading the lesson.

Interpreting Tables

1. Recognize What does the negative sign in the electron symbol mean?

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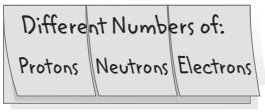
FOLDABLES®

Make a three-tab book to organize the three ways that atoms can differ.



Reading Check

2. Identify What two numbers can be used to identify an element?

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Visual Check

3. Apply Explain the difference between an oxygen atom and a carbon atom.

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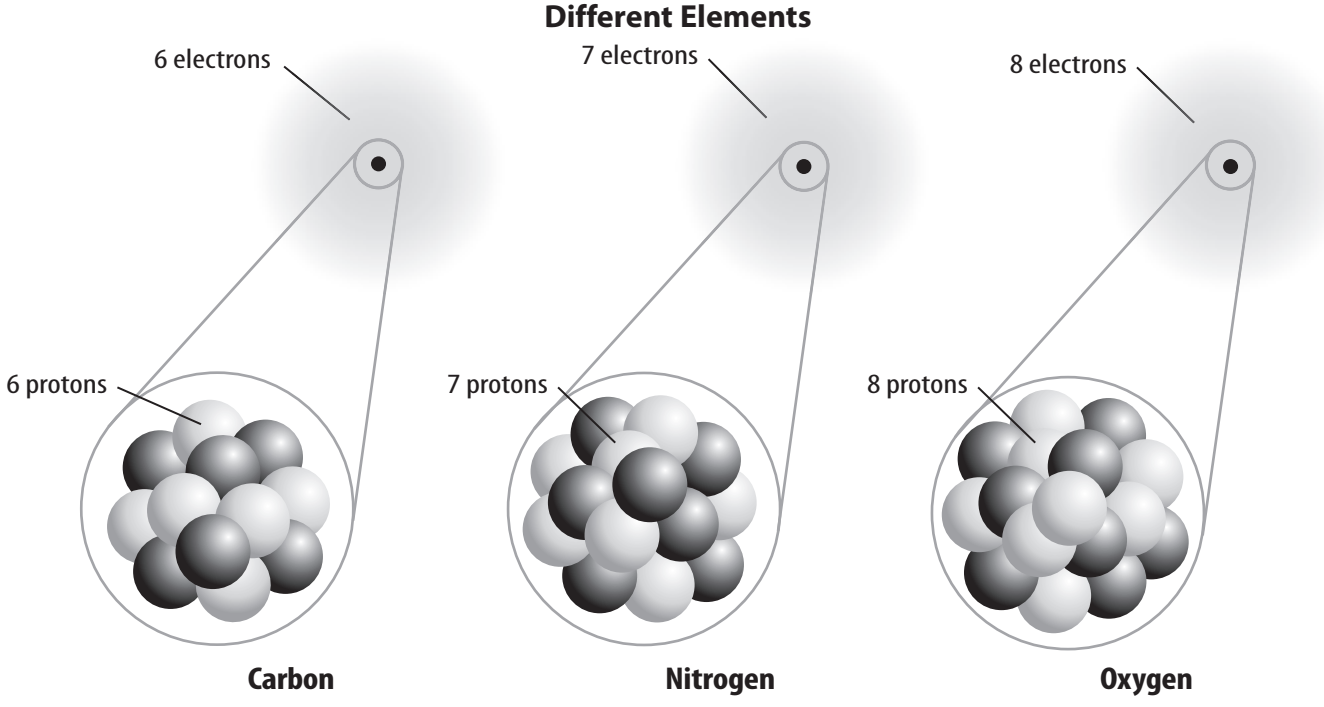
Different Elements—Different Numbers of Protons

Look at the periodic table on the inside back cover of this book. Notice that more than 115 different elements have been identified. Recall that an element is a substance made from atoms that all have the same number of protons. For example, the element carbon is made from atoms that all have six protons. Likewise, all atoms that have six protons are carbon atoms. *The number of protons in an atom of an element is the element's* **atomic number.** The atomic number is the whole number listed with each element on the periodic table.

What makes an atom of one element different from an atom of another element? Atoms of different elements contain different numbers of protons. The number of protons is the element's atomic number. Therefore, different elements have different atomic numbers. For example, an oxygen atom has eight protons. Its atomic number is eight. If an atom has seven protons, it is a nitrogen atom, and its atomic number is seven.

Neutral atoms of different elements also have different numbers of electrons. In a neutral atom, the number of electrons equals the number of protons. Thus, the number of positive charges equals the number of negative charges. The figure below illustrates three neutral atoms. Each atom has the same number of electrons as protons.



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Neutrons and Isotopes

You have read that atoms of the same element have the same numbers of protons. However, atoms of the same element can have different numbers of neutrons. For example, all carbon atoms have six protons. However, some carbon atoms have six neutrons, some have seven neutrons, and some have eight neutrons. These three different types of carbon atoms, shown in the table below, are called isotopes. **Isotopes** *are atoms of the same element that have different numbers of neutrons*. Most elements have several isotopes.

Naturally Occurring Isotopes of Carbon

Isotope	Carbon-12	Carbon-13	Carbon-14
Abundance	98.89%	<1.11%	<0.01%
Protons	6	6	6
Neutrons	+ 6	+ 7	+ 8
Mass Number	12	13	14

Protons, Neutrons, and Mass Number

The **mass number** *of an atom is the sum of the number of protons and neutrons in an atom*. This is shown in the following equation.

mass number = number of protons + number of neutrons

You can determine any one of these three quantities if you know the value of the other two quantities. For example, to determine the mass number of an atom, you must know the number of neutrons and the number of protons in the atom.

The mass numbers of the isotopes of carbon are shown in the table above. An isotope is often written with the element name followed by the mass number. Using this method, the isotopes of carbon are written as carbon-12, carbon-13, and carbon-14.

Average Atomic Mass

You might have noticed that the periodic table does not list mass numbers or the numbers of neutrons. This is because each element can have several isotopes. However, you might notice that a decimal number is listed with most elements. This decimal number is the average atomic mass of the element. *The* **average atomic mass** *of an element is the average mass of the element's isotopes, weighted according to the abundance of each isotope*.

Interpreting Tables

4. Recognize Why do the isotopes of carbon in the table have different mass numbers?

Math Skills

You can calculate the average atomic mass of an element if you know the percentage of each isotope in the element. Lithium (Li) contains 7.5% Li-6 and 92.5% Li-7. What is the average atomic mass of Li?

a. Divide each percentage by 100 to change to decimal form.

$$\frac{7.5\%}{100} = 0.075$$

$$\frac{92.5\%}{100} = 0.925$$

b. Multiply the mass of each isotope by its decimal percentage.

$$6 \times 0.075 = 0.45$$

$$7 \times 0.925 = 6.475$$

c. Add the values together to get the average atomic mass.

$$0.45 + 6.475 = 6.93$$

5. Use Percentages Nitrogen (N) contains 99.63% N-14 and 0.37% N-15. What is the average atomic mass of nitrogen?

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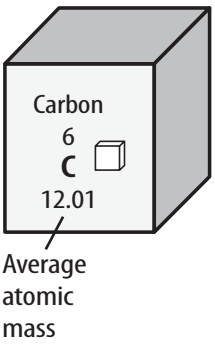
Visual Check

6. Identify What properties of carbon were averaged to arrive at the 12.01 average atomic mass?

Average Atomic Mass



The figure on the left shows the block for carbon from the periodic table. It shows that the average atomic mass of carbon is 12.01. The table on the previous page shows that carbon has three isotopes. Why isn't the average atomic mass 13? After all, the average of the mass numbers 12, 13, and 14 is 13. The average atomic mass is weighted based on each isotope's abundance—how much of each isotope is present on Earth. Almost 99 percent of Earth's carbon is carbon-12, so the average atomic mass is close to 12.

Radioactivity

More than 1,000 years ago, people tried to change lead into gold by performing chemical reactions. However, they did not succeed. Why not? Today, scientists know that a chemical reaction does not change the number of protons in an atom's nucleus. If the number of protons does not change, the element does not change. But in the late 1800s, scientists discovered that some elements change into other elements spontaneously. How does this happen?

ACADEMIC VOCABULARY

spontaneous
(adjective) occurring without external force or cause

Reading Check

7. State Why can't scientists change lead into gold through a chemical reaction?

An Accidental Discovery

In 1896, a scientist named Henri Becquerel (1852–1908) studied minerals containing the element uranium. When these minerals were exposed to sunlight, they gave off a type of energy that could pass through paper. If Becquerel covered a photographic plate with black paper, this energy would pass through the paper and expose the film. An image of the mineral appeared on the plate. One day, Becquerel left the mineral in a drawer next to a wrapped, unexposed plate. Later, he unwrapped the plate and found that it contained an image of the mineral. The mineral spontaneously emitted energy, even in the dark! What was this energy?

Radioactivity

Becquerel shared his discovery with fellow scientists Pierre and Marie Curie. Marie Curie (1867–1934) called *elements that spontaneously emit radiation* **radioactive.** Becquerel and the Curies discovered that the radiation released by uranium was made of energy and particles. This radiation came from the nuclei of the uranium atoms. When this happens, the number of protons in one atom of uranium changes. When uranium releases radiation, it changes to a different element!

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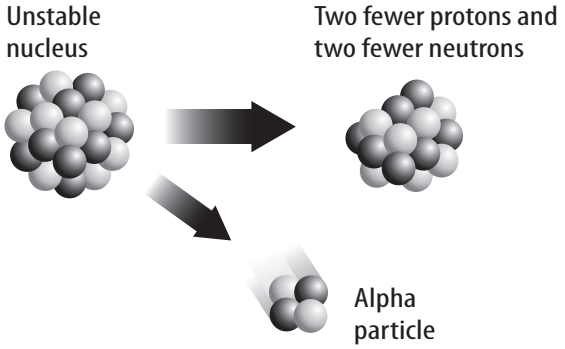
Types of Decay

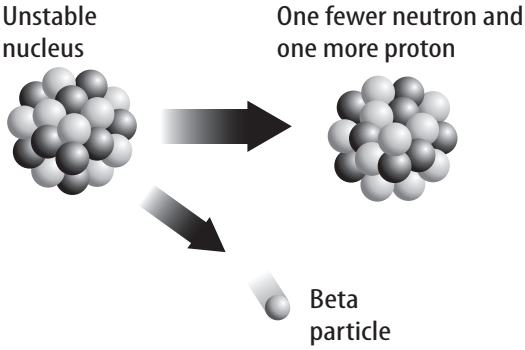
Elements that are radioactive contain unstable nuclei. **Nuclear decay** *is a process that occurs when an unstable atomic nucleus changes into another more stable nucleus by emitting radiation*. Nuclear decay can produce three different types of radiation—alpha particles, beta particles, and gamma rays, as shown in the figure below. Alpha and beta decay change one element into another element.

Types of Nuclear Decay

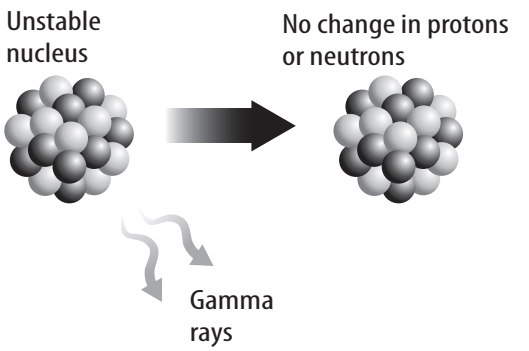
Alpha Decay



Beta Decay



Gamma Decay



Reading Check

8. Name What does an atomic nucleus give off in the process of nuclear decay?

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Visual Check

9. Explain the change in atomic number for each type of decay.

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Alpha Decay An alpha particle is made of two protons and two neutrons. When an atom releases an alpha particle, its atomic number decreases by two. Uranium-238 decays to thorium-234 through the process of alpha decay.

Beta Decay In beta decay, a neutron in an atom changes into a proton and a high-energy electron called a beta particle. The new proton becomes part of the nucleus. The beta particle is released. In beta decay, the atomic number of an atom increases by one because it has gained a proton.

Gamma Decay Gamma rays do not contain particles, but they do contain a lot of energy. In fact, gamma rays can pass through thin sheets of lead! Because gamma rays do not contain particles, the release of gamma rays does not change one element into another element.

Uses of Radioactive Isotopes

The energy released by radioactive decay can be harmful as well as beneficial to humans. Too much radiation can damage or destroy living cells, making them unable to function properly. Some organisms contain cells, such as cancer cells, that are harmful to the organism. Radiation therapy can be beneficial to humans by destroying these harmful cells.

Ions—Gaining or Losing Electrons

What happens to a neutral atom if it gains or loses electrons? Recall that a neutral atom has no overall charge. This is because it contains equal numbers of positively charged protons and negatively charged electrons. When electrons are added to or removed from an atom, that atom becomes an ion. *An* **ion** *is an atom that is no longer neutral because it has gained or lost electrons*. An ion can be positively or negatively charged, depending on whether it has lost or gained electrons.

Positive Ions

When a neutral atom loses one or more electrons, it has more protons than electrons. As a result, it has a positive charge. An atom with a positive charge is called a positive ion. A superscript plus sign ($^+$) following the element's symbol represents a positive ion. For example, the top half of the figure on the next page shows how sodium (Na) becomes a positive sodium ion (Na^+).

Key Concept Check

10. Describe What happens during radioactive decay?

Think it Over

11. Apply Why do people who work with radioactive materials wear special protective clothing?

Reading Check

12. Differentiate How is an ion different from a neutral atom?

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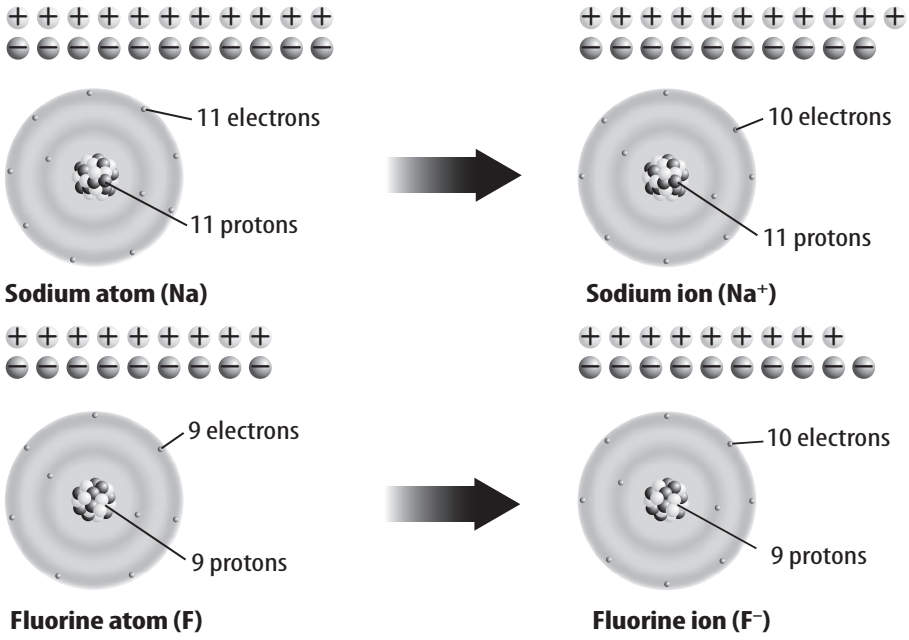
Formation of Positive and Negative Ions



Negative Ions

When a neutral atom gains one or more electrons, it has more electrons than protons. As a result, the atom has a negative charge. An atom with a negative charge is called a negative ion. A superscript negative sign ($^-$) following the element's symbol represents a negative ion. The bottom half of the figure above shows how fluorine (F) becomes a fluorine ion (F^-).

Visual Check

13. Evaluate Why does a fluorine ion have a negative charge?

Key Concept Check

14. Explain How does a neutral atom change when its number of protons, electrons, or neutrons changes?

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Mini Glossary

atomic number: the number of protons in an atom of an element

average atomic mass: the average mass of the element's isotopes, weighted according to the abundance of each isotope

ion: an atom that is no longer neutral because it has gained or lost electrons

isotope: an atom of the same element that has a different number of neutrons

mass number: the sum of the number of protons and neutrons in an atom

nuclear decay: a process that occurs when an unstable atomic nucleus changes into another more stable nucleus by emitting radiation

radioactive: spontaneously emits radiation

1. Review the terms and their definitions in the Mini Glossary. Write a sentence that explains how to determine the number of neutrons in an isotope that has 6 protons and a mass number of 13.

2. Write the symbol or expression that represents each particle or atom in the table.

Particle or Atom	Symbol or Expression
an electron	e^-
a proton	
a neutron	
the carbon isotope with a mass number of 12	carbon-12
the lithium isotope with a mass number of 6	
a positive sodium ion	
a negative fluorine ion	

3. If you could look inside an atom, what would you see?

What do you think NOW?

Reread the statements at the beginning of the lesson. Fill in the After column with an A if you agree with the statement or a D if you disagree. Did you change your mind?

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END OF LESSON

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