Lesson 2

Protons, Neutrons, and Electrons—How Atoms Differ

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

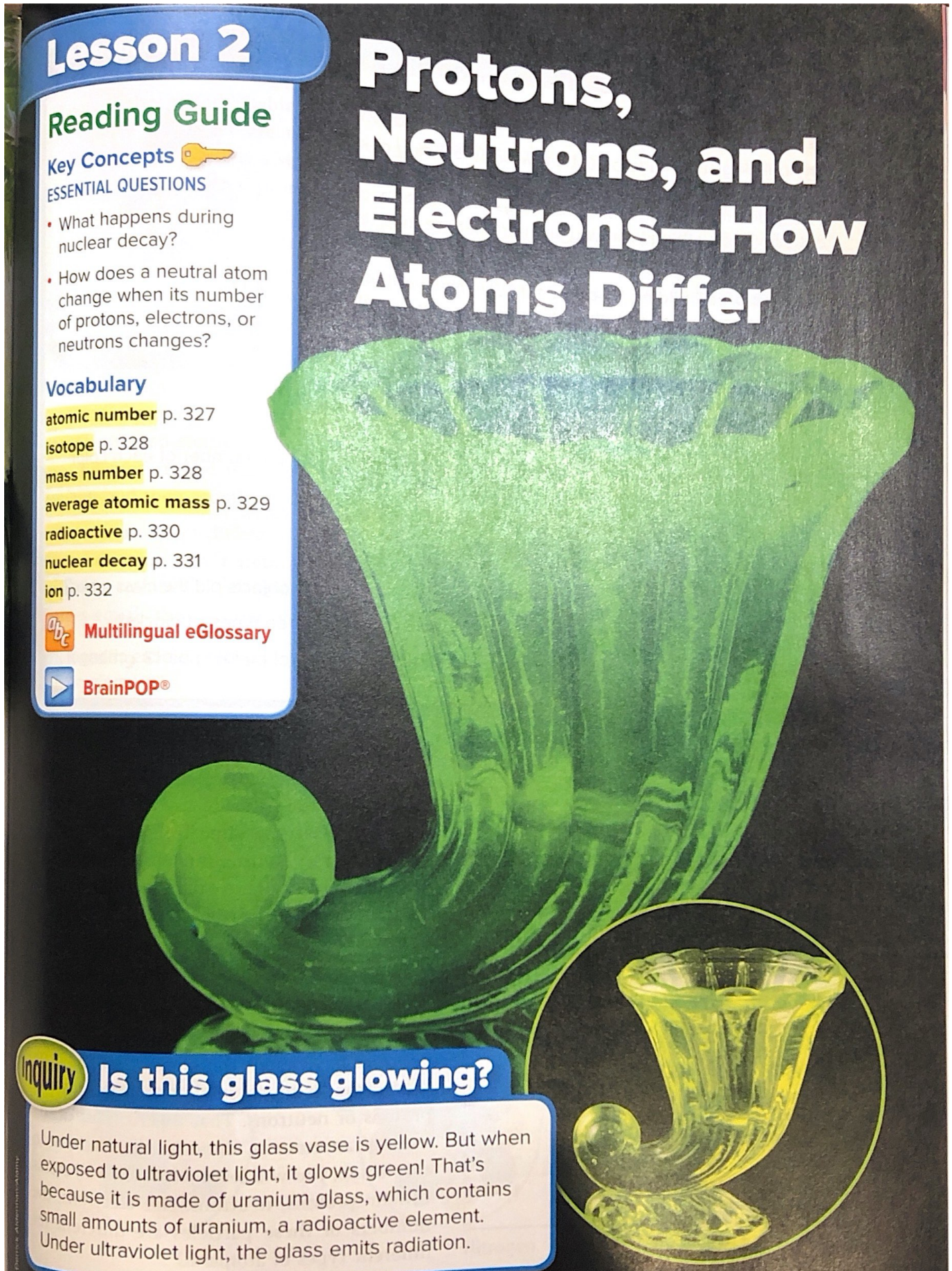
- What happens during nuclear decay?
- How does a neutral atom change when its number of protons, electrons, or neutrons changes?

Vocabulary

atomic number p. 327
isotope p. 328
mass number p. 328
average atomic mass p. 329
radioactive p. 330
nuclear decay p. 331
ion p. 332

Multilingual eGlossary

BrainPOP®



Inquiry Is this glass glowing?

Under natural light, this glass vase is yellow. But when exposed to ultraviolet light, it glows green! That's because it is made of uranium glass, which contains small amounts of uranium, a radioactive element. Under ultraviolet light, the glass emits radiation.

Launch Lab

15 minutes

How many different things can you make?

Many buildings are made of just a few basic building materials, such as wood, nails, and glass. You can combine those materials in many different ways to make buildings of various shapes and sizes. How many things can you make from three materials?

1. Read and complete a lab safety form.
2. Use **colored building blocks** to make as many different objects as you can with the following properties:
   - Each object must have a different number of red blocks.
   - Each object must have an equal number of red and blue blocks.
   - Each object must have at least as many yellow blocks as red blocks but can have no more than two extra yellow blocks.
3. As you complete each object, record in your Science Journal the number of each color of block used to make it. For example, R = 1; B = 1; Y = 2.
4. When time is called, compare your objects with others in the class.

Think About This

1. How many different objects did you make? How many different objects did the class make?
2. How many objects do you think you could make out of the three types of blocks?
3. **Key Concept** In what ways does changing the number of building blocks change the properties of the objects?

Table 2 Properties of Protons, Neutrons, and Electrons

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

The Parts of the Atom

If you could see inside any atom, you probably would see the same thing–empty space surrounding a very tiny nucleus. A look inside the nucleus would reveal positively charged protons and neutral neutrons. Negatively charged electrons would be whizzing by in the empty space around the nucleus.

Table 2 compares the properties of protons, neutrons, and electrons. Protons and neutrons have about the same mass. The mass of electrons is much smaller than the mass of protons or neutrons. That means most of the mass of an atom is found in the nucleus. In this lesson, you will learn that, while all atoms contain protons, neutrons, and electrons, the numbers of these particles are different for different types of atoms.

Different Elements—Different Numbers of Protons

Look at the periodic table on the inside back cover of this book. Notice that there are more than 115 different elements. 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.

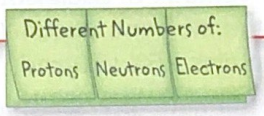
What makes an atom of one element different from an atom of another element? Atoms of different elements contain different numbers of protons. For example, oxygen atoms contain eight protons; nitrogen atoms contain seven protons. Different elements have different atomic numbers. Figure 11 shows some common elements and their atomic numbers.

Neutral atoms of different elements also have different numbers of electrons. In a neutral atom, the number of electrons equals the number of protons. Therefore, the number of positive charges equals the number of negative charges.

Reading Check What two numbers can be used to identify an element?

FOLDABLES®

Create a three-tab book and label it as shown. Use it to organize the three ways that atoms can differ.



Different Elements Personal Tutor

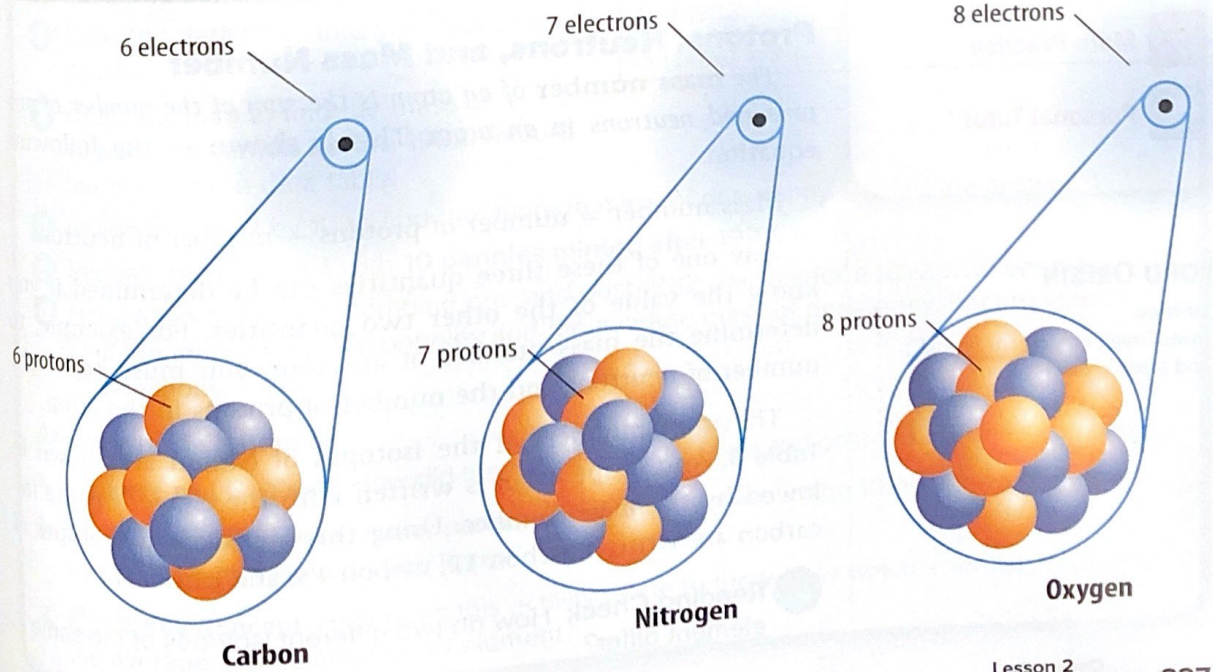


Figure 11 Atoms of different elements contain different numbers of protons.

Visual Check Explain the difference between an oxygen atom and a carbon atom.

Math Skills

Use Percentages

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?

1. Divide each percentage by 100 to change to decimal form.
   $\frac{7.5\%}{100} = 0.075$
   $\frac{92.5\%}{100} = 0.925$
2. Multiply the mass of each isotope by its decimal percentage.
   $6 \times 0.075 = 0.45$
   $7 \times 0.925 = 6.475$
3. Add the values together to get the average atomic mass.
   $0.45 + 6.475 = 6.93$

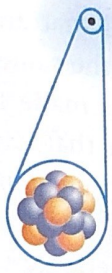
Practice

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

Math Practice

Personal Tutor

Table 3 Naturally Occurring Isotopes of Carbon

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

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, carbon atoms all have six protons, but some carbon atoms have six neutrons, some have seven neutrons, and some have eight neutrons. These three different types of carbon atoms, shown in Table 3, are called isotopes. **Isotopes** *are atoms of the same element that have different numbers of neutrons.* Most elements have several isotopes.

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

Any one of these three quantities can be determined 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 Table 3. An isotope often is written with the element name followed by the mass number. Using this method, the isotopes of carbon are written carbon-12, carbon-13, and carbon-14.

Reading Check How do two different isotopes of the same element differ?

WORD ORIGIN

isotope
from Greek *isos*, means "equal"; and *topos*, means "place"

Average Atomic Mass

You might have noticed that the periodic table does not list mass numbers or the numbers of neutrons. This is because a given element can have several isotopes. However, you might notice that there is a decimal number listed with most elements, as shown in Figure 12. 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.*

Table 3 shows the three isotopes of carbon. The average atomic mass of carbon is 12.01. 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. That is why the average atomic mass is close to 12.

Reading Check What does the term *weighted average* mean?

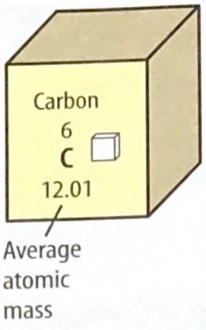


Figure 12 The element carbon has several isotopes. The decimal number 12.01 is the average atomic mass of these isotopes.

MiniLab

20 minutes

How many penny isotopes do you have?

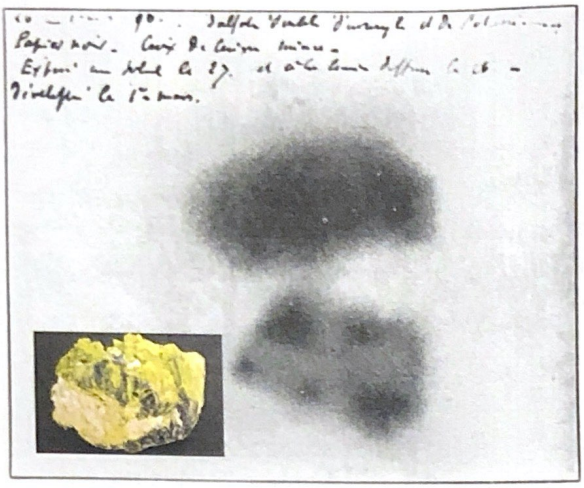
All pennies look similar, and all have a value of one cent. But do they have the same mass? Let's find out.

1. Read and complete a lab safety form.
2. Copy the data table into your Science Journal.
3. Use a **balance** to find the mass of **10 pennies minted before 1982.** Record the mass in the data table.
4. Divide the mass by 10 to find the average mass of one penny. Record the answer.
5. Repeat steps 3 and 4 with **10 pennies minted after 1982.**
6. Have a team member combine pre- and post-1982 pennies for a total of 10 pennies. Find the mass of the ten pennies and the average mass of one penny. Record your observations.

Penny Sample	Mass of 10 pennies (g)	Average mass of 1 penny (g)
Pre-1982		
Post-1982		
Unknown mix		

Analyze and Conclude

1. **Compare and Contrast** How did the average mass of pre- and post-1982 pennies compare?
2. **Draw Conclusions** How many pennies of each type were in the 10 pennies assembled by your partner? How do you know?
3. **Key Concept** How does this activity relate to the way in which scientists calculate the average atomic mass of an element?



▲ **Figure 13** The black and white photo shows Henri Becquerel's photographic plate. The dark area on the plate was exposed to radiation given off by uranium in the mineral even though the mineral was not exposed to sunlight.

ACADEMIC VOCABULARY

spontaneous
(adjective) occurring without external force or cause

Figure 14 Marie Curie studied radioactivity and discovered two new radioactive elements—polonium and radium. ▼

Radioactivity

More than 1,000 years ago, people tried to change lead into gold by performing chemical reactions. However, none of their reactions were successful. 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?

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. One day, Becquerel left the mineral next to a wrapped, unexposed plate in a drawer. Later, he opened the drawer, unwrapped the plate, and saw that the plate contained an image of the mineral, as shown in **Figure 13.** The mineral spontaneously emitted energy, even in the dark! Sunlight wasn't required. What was this energy?

Radioactivity

Becquerel shared his discovery with fellow scientists Pierre and Marie Curie. Marie Curie (1867-1934), shown in **Figure 14,** 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!

Types of Decay

Radioactive elements 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. **Figure 15** compares the three types of nuclear decay.

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 When beta decay occurs, 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, and 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.

Key Concept Check What happens during radioactive decay?

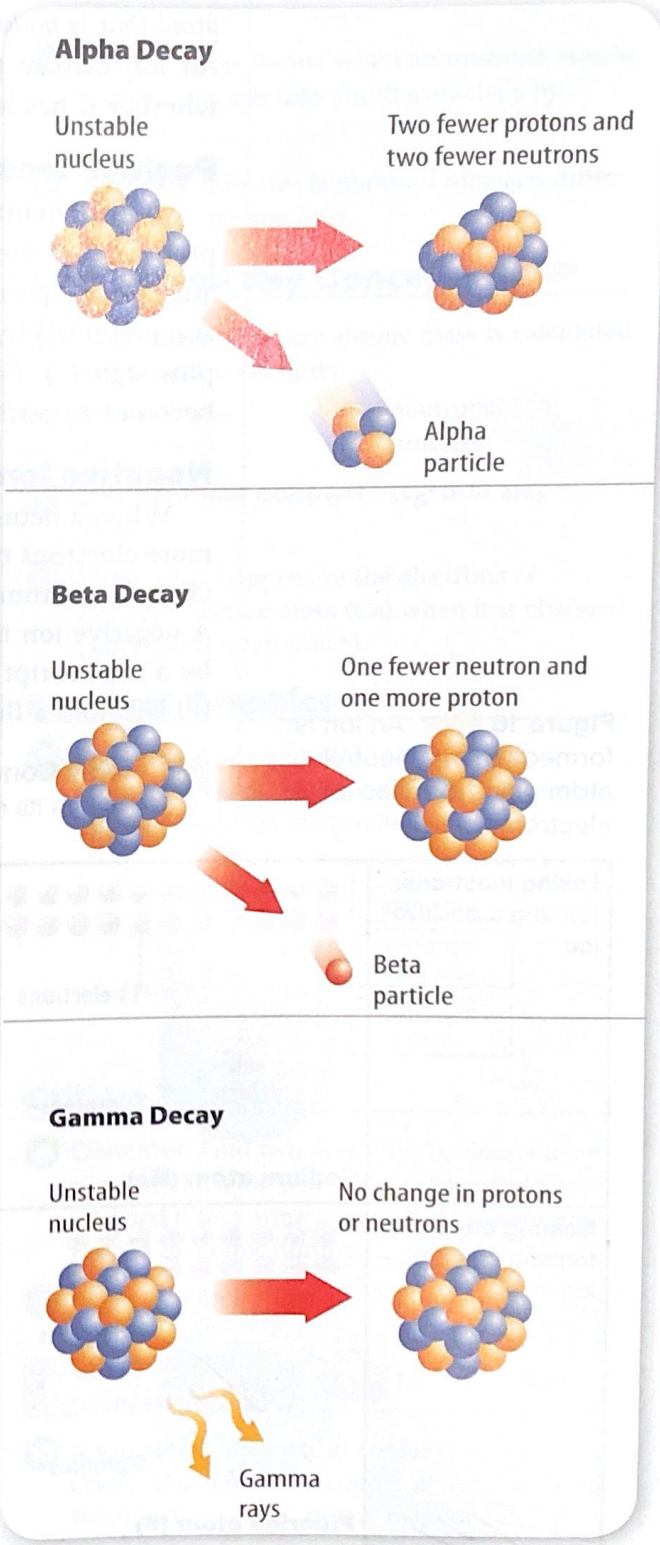
Uses of Radioactive Isotopes

The energy released by radioactive decay can be both harmful and 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.

Animation

Figure 15 Alpha and beta decay change one element into another element.

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



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 positive ion is represented by the element's symbol followed by a superscript plus sign ($^+$). For example, **Figure 16** shows how sodium (Na) becomes a positive sodium ion (Na^+).

Negative Ions

When a neutral atom gains one or more electrons, it now 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 negative ion is represented by the element's symbol followed by a superscript negative sign ($^-$). **Figure 16** shows how fluorine (F) becomes a fluoride ion (F^-).

Key Concept Check How does a neutral atom change when its number of protons, electrons, or neutrons changes?

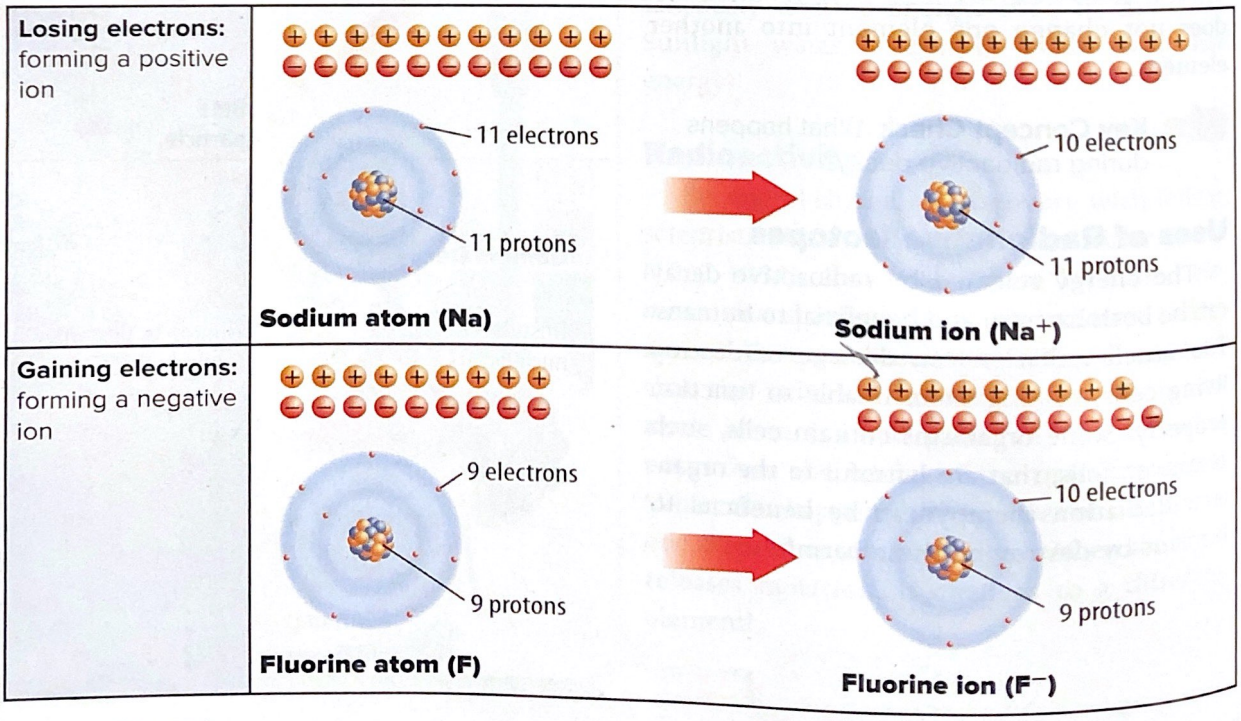


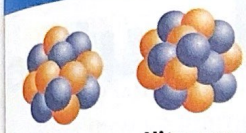
Figure 16 An ion is formed when a neutral atom gains or loses an electron.

Lesson 2 Review

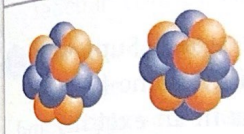
Online Quiz

Virtual Lab

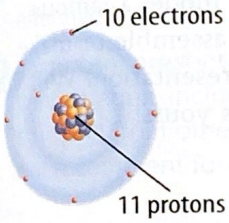
Visual Summary



Different elements contain different numbers of protons.



Two isotopes of a given element contain different numbers of neutrons.



When a neutral atom gains or loses an electron, it becomes an ion.

FOLDABLES

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

What do you think NOW?

You first read the statements below at the beginning of the chapter.

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.

Did you change your mind about whether you agree or disagree with the statements? Rewrite any false statements to make them true.

Use Vocabulary

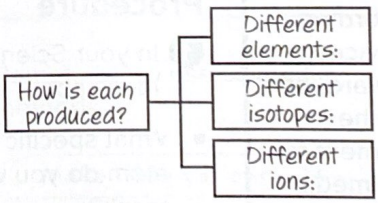
1. The number of protons in an atom of an element is its _____.
2. Nuclear decay occurs when an unstable atomic nucleus changes into another nucleus by emitting _____.
3. **Describe** how two isotopes of nitrogen differ from two nitrogen ions.

Understand Key Concepts

4. An element's average atomic mass is calculated using the masses of its
   - A. electrons.
   - B. isotopes.
   - C. neutrons.
   - D. protons.
5. **Compare and contrast** oxygen-16 and oxygen-17.
6. **Show** what happens to the electrons of a neutral calcium atom (Ca) when it is changed into a calcium ion (Ca^{2+}).

Interpret Graphics

7. **Contrast** Copy and fill in this graphic organizer to contrast how different elements, isotopes, and ions are produced.



Critical Thinking

8. **Consider** Find two neighboring elements on the periodic table whose positions would be reversed if they were arranged by atomic mass instead of atomic number.
9. **Infer** Can an isotope also be an ion?

Math Skills

Math Practice

10. A sample of copper (Cu) contains 69.17% Cu-63. The remaining copper atoms are Cu-65. What is the average atomic mass of copper?