Section 4.2

1 FOCUS

Objectives

4.2.1 **Identify** three subatomic particles and **compare** their properties.

4.2.2 **Distinguish** the atomic number of an element from the mass number of an isotope, and use these numbers to **describe** the structure of atoms.

Reading Focus

Build Vocabulary L2

Word-Part Analysis Have students look up the term *isotope* in a dictionary that provides word prefixes. Have them use the prefix *iso-* to help them understand the term. *(The prefix* iso- *means "same." Isotopes of an element have the same atomic number, but different numbers of neutrons.)*

Reading Strategy L2

Most students will know that atoms are the "building blocks" of matter, and some may know that atoms contain subatomic particles. Students may say that they want to learn more about the structure of atoms.

2 INSTRUCT

Properties of Subatomic Particles

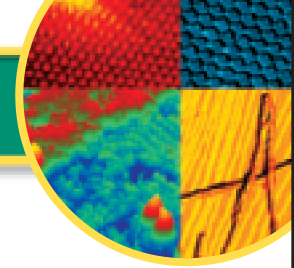
Use Visuals L1

Figure 9 Have students examine the photo and the caption that describes it in Figure 9. Suggest some familiar objects that have a mass of 5 kg, such as a 12-pack of 16-ounce beverage containers. Ask, **If a proton's mass was 10 tons and an electron's mass was 5 kg, what mass would represent the mass of a neutron?** *(10 tons)*
Logical

FYI

Different books use different conventions for symbols for subatomic particles. For example, some texts use only the letters *e*, *p*, and *n*. Others include a superscript zero on the *n* to indicate the lack of charge. Electrons, protons, and neutrons are not the only subatomic particles. Quarks will be discussed in Chapter 10.

4.2 The Structure of an Atom



Reading Focus

Key Concepts

- What are three subatomic particles?
- What properties can be used to compare protons, electrons, and neutrons?
- How are atoms of one element different from atoms of other elements?
- What is the difference between two isotopes of the same element?

Vocabulary

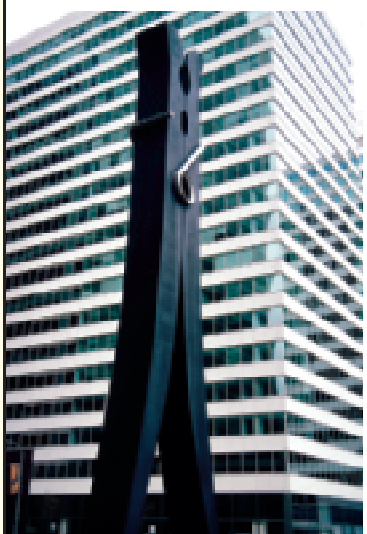
- proton
- electron
- neutron
- atomic number
- mass number
- isotopes

Reading Strategy

Monitoring Your Understanding Before you read, copy the table. List what you know about atoms and what you would like to learn. After you read, list what you have learned.

What I Know About Atoms	What I Would Like to Learn	What I Have Learned

Figure 9 This 45-foot-tall steel sculpture of a clothespin is in Philadelphia, Pennsylvania. Claes Oldenburg made the clothespin in 1976 from 10 tons of steel. If a proton had a mass of 10 tons, then an electron would have a mass of about 5 kilograms.



Beams like the ones Thomson produced create the images on many television screens. When a beam sweeps across the screen, spots on the screen light up in the same way the screen in the gold-foil experiment lit up when struck by an alpha particle. In a color television, there are three beams, one for each primary color of light—red, green, and blue. The particles in these beams are subatomic particles.

Properties of Subatomic Particles

By 1920, Rutherford had seen evidence for the existence of two subatomic particles and had predicted the existence of a third particle. **Protons, electrons, and neutrons are subatomic particles.**

Protons Based on experiments with elements other than gold, Rutherford concluded that the amount of positive charge varies among elements. Each nucleus must contain at least one particle with a positive charge. Rutherford called these particles protons. A **proton** is a positively charged subatomic particle that is found in the nucleus of an atom. Each proton is assigned a charge of 1+. Some nuclei contain more than 100 protons.

Electrons The particles that Thomson detected were later named electrons. *Electron* comes from a Greek word meaning "amber." An **electron** is a negatively charged subatomic particle that is found in the space outside the nucleus. Each electron has a charge of 1−.

Section Resources

Print

- ***Reading and Study Workbook With Math Support***, Section 4.2 and **Math Skill:** Electrons and Orbitals
- ***Transparencies***, Section 4.2

Technology

- ***Interactive Textbook***, Section 4.2
- ***Presentation Pro CD-ROM***, Section 4.2
- ***Go Online***, *Science News*, Atomic chemistry

Properties of Subatomic Particles					
Particle	**Symbol**	**Relative Charge**	**Relative Mass (proton = 1)**	**Actual Mass (g)**	**Model**
Electron	e^-	1−	$\frac{1}{1836}$	9.11×10^{-28}	(yellow sphere)
Proton	p^+	1+	1	1.674×10^{-24}	(green sphere)
Neutron	n	0	1	1.675×10^{-24}	(purple sphere)

Figure 10 This table lists the symbol, the relative charge, the relative mass, and the actual mass of an electron, a proton, and a neutron. The Model column shows the colors used in this book to represent the subatomic particles. **Calculating** ***What is the difference in actual mass between a proton and a neutron?***

Neutrons In 1932, the English physicist James Chadwick designed an experiment to show that neutrons exist. Chadwick concluded that the particles he produced were neutral because a charged object did not deflect their paths. A **neutron** is a neutral subatomic particle that is found in the nucleus of an atom. It has a mass almost exactly equal to that of a proton.

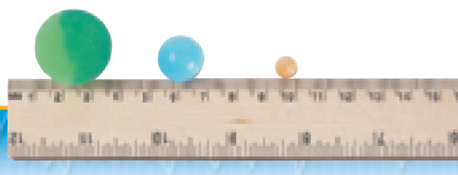
Comparing Subatomic Particles

Figure 10 summarizes some properties of protons, electrons, and neutrons. **Protons, electrons, and neutrons can be distinguished by mass, charge, and location in an atom.** Protons and neutrons have almost the same mass. But the data in Figure 10 show that it would take about 2000 electrons to equal the mass of one proton. Electrons have a charge that is equal in size to, but the opposite of, the charge of a proton. Neutrons have no charge. Protons and neutrons are found in the nucleus, but electrons are found in the space outside the nucleus.

Go Online SCIENCE NEWS

For: Articles on atomic chemistry
Visit: PHSchool.com
Web Code: cce-1042

Problem-Solving Activity



Designing an Atomic Exhibit

You work as a volunteer at the local science museum. You are asked to design an exhibit that compares the size of a lithium atom to the size of its nucleus. A lithium atom has a diameter of about 3×10^2 picometers. The nucleus of a lithium atom has a diameter of about 5×10^{-3} picometers. There are a trillion (10^{12}) picometers in a meter.

Defining the Problem State the problem in your own words. What decisions will you need to make before you can proceed?

Organizing Information How many times larger is the lithium atom than its nucleus? Find several objects that could represent the nucleus in your exhibit and measure their diameters.

Creating a Solution Pick one of the objects you measured to represent the nucleus in your atomic exhibit. Figure out how far away from the object you would have to place a marker so that people could visualize the relative sizes of the atom and the nucleus.

Presenting Your Plan Write a proposal to present to the committee that approves projects. Tell them where you would place the nucleus and where you would have to place the marker. Be prepared to explain why your exhibit needs the space you are requesting.

Comparing Subatomic Particles

Build Science Skills L2

Calculating Have students confirm the relative masses given in Figure 10 by dividing the mass given for an electron by the mass given for a neutron. *($9.11 \times 10^{-28}/1.675 \times 10^{-24} = 5.44 \times 10^{-4}$; $1/1836 = 5.45 \times 10^{-4}$)* These numbers are almost equal. Note that the masses given are in grams.
Logical

Problem-Solving Activity

Designing an Atomic Exhibit L2

Defining the Problem To design an exhibit that compares the size of a lithium atom to the size of its nucleus, students must decide what materials to use and where to locate the exhibit.

Organizing Information It is 60,000 times larger than its nucleus.

Creating a Solution If a standard marble with a 5/8-inch diameter (1.6 cm) represents the nucleus, the marker should be at a distance of 960 m to represent the outer limit of the atom.

Presenting Your Plan The proposal should explain why the exhibit requires at least two locations that are about a kilometer apart to make a model of the lithium atom in which the nucleus is the size of a marble. Encourage students to locate two familiar area landmarks that are the appropriate distance apart based on the item chosen for the nucleus.
Visual, Logical

For Extra Help L1

Be sure that students multiply by the conversion factor that has the given unit in the denominator and the desired unit in the numerator.
Logical

Customize for Inclusion Students

Visually Impaired
Provide visually impaired students with a tactile model that represents the difference in mass between a proton and an electron. Count out (or have a group of students count out) 1836 small beads and place them into a resealable plastic bag. Have them feel the difference in mass between the bag of 1836 beads and an identical bag containing only one bead. Point out that the masses they sense include the masses of the bags.

Go Online SCIENCE NEWS

Science News provides students with current information on atomic chemistry.

Answer to . . .

Figure 10 *0.001×10^{-24} g*

Atomic Number and Mass Number

FYI

The atomic mass unit will be introduced in Section 5.2, when atomic masses listed in the periodic table are discussed. The force that binds protons and neutrons together in the nucleus is called the strong nuclear force and is addressed in Chapter 10, as is the effect of the size of a nucleus on its stability.

Teacher Demo

Particles and Numbers L2

Purpose Students will observe the relationship between number of protons, number of neutrons, atomic number, and mass number.

Materials overhead projector, red and green gummy candies

Procedure Explain that the green candies represent neutrons and the red candies represent protons. Model a lithium-7 nucleus by placing a group of three red candies and four green candies on the overhead. Ask students to count the number of candies (particles) to determine the mass number of the lithium atom. Then, remove (subtract) the green candies (neutrons) to get the atomic number. Perform a similar demonstration with oxygen-16 (eight protons and eight neutrons) and boron-11 (five protons and six neutrons).

Expected Outcome Students should gain a familiarity with determining mass numbers and atomic numbers.
Visual

Build Reading Literacy L1

Identify Main Idea/Details Refer to page **98D** in this chapter, which provides the guidelines for identifying main ideas and details.

Have students read Atomic Number and Mass Number on p. 110. Ask them to identify the main idea of each paragraph. Point out that the main idea is usually within the first or second sentence of a paragraph. Encourage students to include this exercise in the notes they use to study.
Verbal

Everything scientists know about the nucleus and subatomic particles is based on how the particles behave. Scientists still do not have an instrument that can show the inside of an atom. But they do have microscopes that can show how atoms are arranged on the surface of a material. The How It Works box on page 111 describes one of those microscopes.

Reading Checkpoint *Which scientist demonstrated the existence of neutrons?*

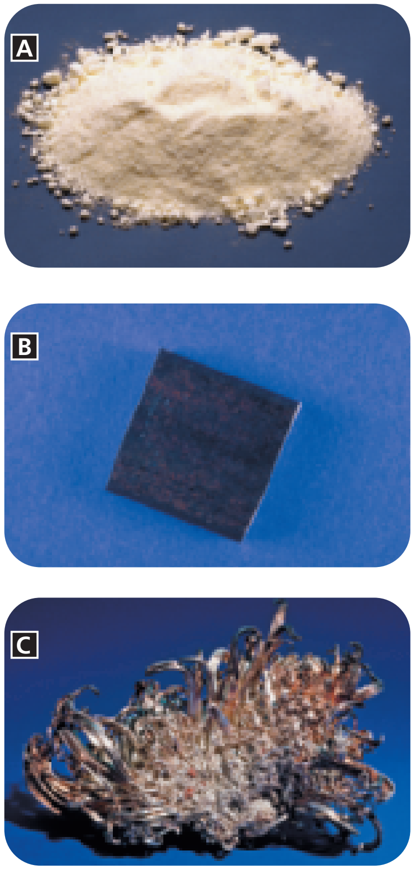


Figure 11 Each element has a different atomic number. **A** The atomic number of sulfur (S) is 16. **B** The atomic number of iron (Fe) is 26. **C** The atomic number of silver (Ag) is 47.
Applying Concepts ***How many protons are there in each atom of sulfur, iron, and silver?***

Atomic Number and Mass Number

Dalton predicted that the atoms of any element are different from the atoms of all other elements. With the discovery of subatomic particles, scientists were able to describe those differences.

Atomic Number The atoms of any given element always have the same number of protons. For example, there is one proton in the nucleus of each and every hydrogen atom. Therefore, hydrogen is assigned the atomic number 1. The **atomic number** of an element equals the number of protons in an atom of that element.

Hydrogen atoms are the only atoms with a single proton. **Atoms of different elements have different numbers of protons.** The sulfur shown in Figure 11A is assigned atomic number 16 because a sulfur atom has 16 protons. You can use atomic numbers to refer to elements, like names and symbols, because each element has a unique atomic number.

Each positive charge in an atom is balanced by a negative charge because atoms are neutral. So the atomic number of an element also equals the number of electrons in an atom. Each hydrogen atom has one electron. Each sulfur atom has 16.

Mass Number The atomic number tells you the number of protons in an atom's nucleus. It does not give you any information about the number of neutrons in an atom. For that information, you need to know the atom's mass number. The **mass number** of an atom is the sum of the protons and neutrons in the nucleus of that atom. An atom of aluminum with 13 protons and 14 neutrons has a mass number of 27. If you know the atomic number and the mass number of an atom, you can find the number of neutrons by subtracting.

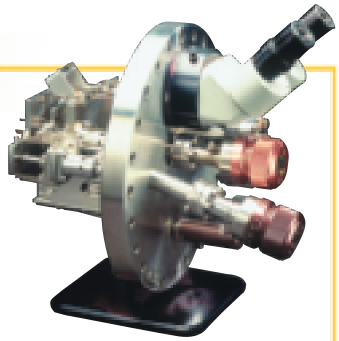
Number of Neutrons

Number of neutrons = Mass number − Atomic number

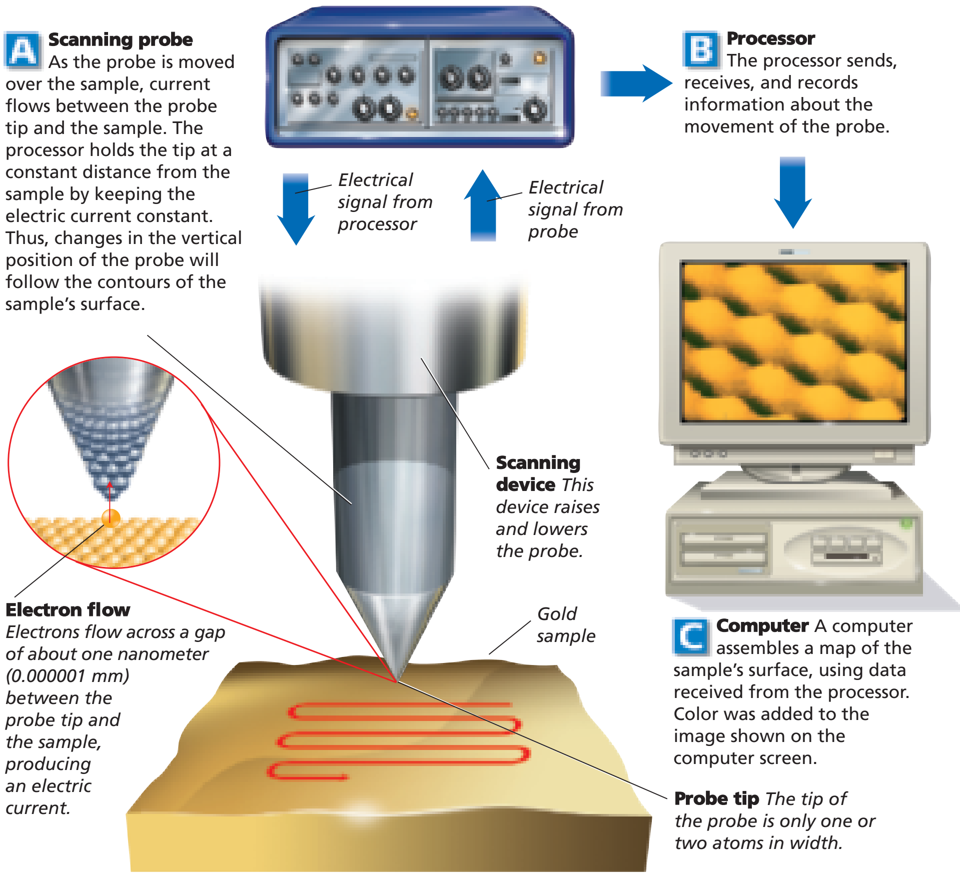
HOW It Works

Scanning Tunneling Microscope

A probe is moved back and forth across the surface of a sample. When electrons jump, or tunnel, across the gap between the sample and the probe, an electric current is produced. A computer uses data about changes in the probe's position to produce an image of the sample's surface. **Interpreting Diagrams** ***How is the distance between the probe tip and the sample kept constant?***



Scanning tunneling microscope
Modern scanning tunneling microscopes produce images of metal samples or biological specimens such as DNA.



A Scanning probe As the probe is moved over the sample, current flows between the probe tip and the sample. The processor holds the tip at a constant distance from the sample by keeping the electric current constant. Thus, changes in the vertical position of the probe will follow the contours of the sample's surface.

B Processor The processor sends, receives, and records information about the movement of the probe.

C Computer A computer assembles a map of the sample's surface, using data received from the processor. Color was added to the image shown on the computer screen.

Scanning device *This device raises and lowers the probe.*

Electron flow *Electrons flow across a gap of about one nanometer (0.000001 mm) between the probe tip and the sample, producing an electric current.*

Probe tip *The tip of the probe is only one or two atoms in width.*

HOW It Works

Scanning Tunneling Microscope L2

The scanning tunneling microscope (STM) is used to obtain high-resolution images of solid surfaces. This technology allows scientists and researchers to view a three-dimensional profile of a surface, which can give information about surface textures and crystal structure. STM data is initially displayed as a black and white image that is colorized to highlight different features.

In 1986, Gerd Binnig of Germany and Heinrich Rohrer of Switzerland shared the Nobel Prize in Physics with Germany's Ernst Ruska for designing the scanning tunneling microscope.

Interpreting Diagrams The processor maintains a constant electric current between the probe tip and the sample, which keeps the distance between the tip and sample constant.
Logical

For Enrichment L3

Encourage students to explore the use of scanning tunneling microscopes in research on surface textures, crystal structure, or molecular shape. Have them present their findings to the class in the form of a poster.
Visual

Facts and Figures

Coining Terms The English physician William Gilbert (1544–1603) introduced the term *electric*, which is based on the Greek word for amber. (William Gilbert was the personal physician to Queen Elizabeth I and a pioneer in the study of magnetism. A unit of magnetic force is named for him.) Credit for naming the electron goes to G. Johnstone Stoney, an Irish physicist who suggested the name in 1891.

Answer to . . .

Figure 11 *There are 16 protons in a sulfur atom, 26 in an iron atom, and 47 in a silver atom.*

Reading Checkpoint *James Chadwick*

Section 4.2 (continued)

Isotopes

Build Science Skills L2

Calculating Uranium-238 has a mass number of 238 with 146 neutrons in the nucleus. Uranium-235 has 143 neutrons in the nucleus. Ask, **What is the atomic number of uranium?** *(92)*
Logical

Address Misconceptions L2

Many students think that isotopes are different from "ordinary" or "regular" atoms. To challenge this misconception, have students read the text on this page and examine the data presented in Figure 12. Ask, **How are the compositions of heavy water and ordinary water similar?** *(Both contain hydrogen and oxygen atoms.)* **What type of hydrogen atoms does ordinary water contain?** *(Hydrogen-1 atoms)* **What type of hydrogen atoms does heavy water contain?** *(Hydrogen-2 atoms)* **Compare the properties of heavy water and ordinary water.** *(They have different melting points, boiling points, and densities.)*
Logical

3 ASSESS

Evaluate Understanding L2

Have students write three review questions for this section. Students should then break into groups of three or four and ask each other their questions.

Reteach L1

Revisit Figure 10 to review the differences among protons, neutrons, and electrons.

Connecting Concepts

Students might say that "type of atom" refers to the atomic number of the atom or to the number of protons in the atom.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 4.2.

Answer to . . .

Figure 12 *3.81°C*

Comparing Ordinary Water and Heavy Water

Property	Ordinary Water	Heavy Water
Melting point	0.00°C	3.81°C
Boiling point	100.00°C	101.42°C
Density (at 25°C)	0.99701 g/cm^3	1.1044 g/cm^3

Figure 12 Heavy water contains hydrogen-2 atoms, which have twice the mass of hydrogen-1 atoms. **Using Tables** ***At what temperature would a sample of heavy water freeze?***

Isotopes

In Dalton's atomic theory, all the atoms of a given element are identical. Every atom of a given element *does* have the same number of protons and electrons. But every atom of a given element *does not* have the same number of neutrons. **Isotopes** are atoms of the same element that have different numbers of neutrons and different mass numbers. **Isotopes of an element have the same atomic number but different mass numbers because they have different numbers of neutrons.**

For example, every atom of oxygen has 8 protons. Some oxygen atoms have 8 neutrons and a mass number of 16. Some oxygen atoms have 9 neutrons and a mass number of 17. Some oxygen atoms have 10 neutrons and a mass number of 18. When it is important to distinguish one oxygen isotope from another, the isotopes are referred to as oxygen-16, oxygen-17, and oxygen-18. All three oxygen isotopes can react with hydrogen to form water or combine with iron to form rust.

With most elements, it is hard to notice any differences in the physical or chemical properties of their isotopes. Hydrogen is an exception. Hydrogen-1 has no neutrons. (Almost all hydrogen is hydrogen-1.) Hydrogen-2 has one neutron, and hydrogen-3 has two neutrons. Because a hydrogen-1 atom has only one proton, adding a neutron doubles its mass. Water that contains hydrogen-2 atoms in place of hydrogen-1 atoms is called heavy water. Figure 12 compares some physical properties of ordinary water and heavy water.

Section 4.2 Assessment

Reviewing Concepts

1. Name three subatomic particles.
2. Name three properties you could use to distinguish a proton from an electron.
3. Which characteristic of an atom always varies among atoms of different elements?
4. How are the isotopes of an element different from one another?
5. What do neutrons and protons have in common? How are they different?
6. How can atoms be neutral if they contain charged particles?
7. What is the difference between atoms of oxygen-16 and oxygen-17?

Critical Thinking

8. **Comparing and Contrasting** What property do protons and electrons have that neutrons do not?
9. **Applying Concepts** Explain why it isn't possible for an atom to have a mass number of 10 and an atomic number of 12.

Connecting Concepts

Elements In Section 2.1, you were told that elements contain only one type of atom. How would you define "type of atom" to account for the existence of isotopes?

Section 4.2 Assessment

1. Proton, electron, and neutron
2. Mass, charge, and location in an atom
3. The atoms of any element have a different number of protons than the atoms of all other elements.
4. Isotopes of an element have the same atomic number but different mass numbers because they have different numbers of neutrons.
5. Protons and neutrons have almost the same mass and are both located in the nucleus of the atom. Protons are charged particles. Neutrons are neutral particles.
6. The positive charge of the protons in the nucleus is balanced by the negative charge of the electrons.
7. Each oxygen-17 atom has one more neutron than each oxygen-16 atom.
8. Protons and electrons are charged particles. Neutrons have no charge.
9. An atom with an atomic number of 12 has 12 protons. Because the mass number is the sum of the protons and neutrons, the mass number would need to be at least 12.