4 Atomic Structure

ELECTRONS AND THE STRUCTURE OF ATOMS

4.1 Defining the Atom

**Essential Understanding**
Atoms are the fundamental building blocks of matter.

**Lesson Summary**

**Early Models of the Atom** The scientific study of the atom began with John Dalton in the early 1800s.
- The ancient Greek Democritus first proposed that matter is made up of small, indivisible particles that he called atoms.
- John Dalton made the first accepted theory on atoms almost 2000 years after the work of Democritus.
- Dalton’s atomic theory included that all atoms of an element are alike, the atoms of different elements are different, and atoms can combine to form compounds.

**Sizing up the Atom** Atoms are extremely small, but technology enables scientists to view atoms.
- An atom is the smallest part of an element that has the properties of that element.
- Individual atoms can be seen and even moved around using instruments such as scanning electron microscopes.

**After reviewing part I of the PowerPoint slides, answer the following questions.**

**Early Models of the Atom**

1. Democritus, who lived in Greece during the fourth century B.C., suggested that matter is made up of tiny particles that cannot be divided. He called these particles ________________.

2. List two reasons why the ideas of Democritus were not useful in a scientific sense.

3. The modern process of discovery about atoms began with the theories of an English schoolteacher named ________________.
4. Circle the letter of each sentence that is true about Dalton’s atomic theory.
   a. All elements are composed of tiny, indivisible particles called atoms.
   b. An element is composed of several types of atoms.
   c. Atoms of different elements can physically mix together, or can chemically combine in simple, whole-number ratios to form compounds.
   d. Chemical reactions occur when atoms are separated, joined, or rearranged; however, atoms of one element are never changed into atoms of another element by a chemical reaction.

5. In the diagram, use the labels *mixture* and *compound* to identify the mixture of elements A and B and the compound that forms when the atoms of elements A and B combine chemically.

![Diagram with labels](image)

**Sizing up the Atom**

6. Suppose you could grind a sample of the element copper into smaller and smaller particles. The smallest particle that could no longer be divided, yet still has the chemical properties of copper, is ________________.

7. About how many atoms of copper when placed side by side would form a line 1 cm long? ________________

### 4.2 Structure of the Nuclear Atom

**Essential Understanding** An atom is made up of a nucleus that contains protons and neutrons. Electrons move around the nucleus.

**Reading Strategy**

**Combination Notes** Combination notes help you to convey ideas in words and pictures at the same time. Write “Atomic Structure” at the top of the T on the following page. In the left column, write notes about the subatomic particles. In the right column, draw pictures that help you visualize subatomic particles.
As you review part II of the PowerPoint slides, use the T-Chart Graphic Organizer below to summarize in words and pictures what you know about protons, neutrons, and electrons.

<table>
<thead>
<tr>
<th>Parts of an atom</th>
<th>How I visualize it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons:</td>
<td></td>
</tr>
<tr>
<td>Protons:</td>
<td></td>
</tr>
<tr>
<td>Neutrons:</td>
<td></td>
</tr>
</tbody>
</table>

**EXTENSION** Write linking sentences that show the relationship between protons, neutrons, and electrons.

**Lesson Summary**

**Subatomic Particles** Subatomic particles are made up of protons, neutrons, and electrons.

- Electrons are negatively charged subatomic particles discovered by J. J. Thomson in the late 1800s.
- At about the same time, Eugen Goldstein discovered the proton, which is a positively charged subatomic particle.
- In the 1900s, James Chadwick discovered the neutron, which is a subatomic particle with no charge.

**The Atomic Nucleus** Modern atomic theory states that the protons and neutrons exist at the center of an atom in a small nucleus, and electrons move around this nucleus.

- Thomson proposed an atomic model in which electrons were stuck in a sphere of positive charge.
- The atom is mostly empty space containing a small, dense, positively charged core called the nucleus.
- According to Rutherford’s nuclear atom theory, electrons are distributed around the nucleus and occupy most of the space in an atom.

**After reviewing part II of the PowerPoint slides, answer the following questions.**

**Subatomic Particles**

1. How is the atomic theory that is accepted today different from Dalton’s atomic theory?

2. Which subatomic particles carry a negative charge? ________________
Match each term from the experiments of J. J. Thomson with the correct description.

3. anode
   a. an electrode with a negative charge
4. cathode
   b. a glowing beam traveling between charged electrodes
5. cathode ray
   c. an electrode with a positive charge
6. electron
   d. a negatively charged particle
7. The diagram shows electrons moving from left to right in a cathode-ray tube. Draw an arrow showing how the path of the electrons will be affected by the placement of the negatively and positively charged plates.

8. Thomson observed that the production of cathode rays did not depend on the kind of gas in the tube or the type of metal used for the electrodes. What conclusion did he draw from these observations?

9. What two properties of an electron did Robert Millikan determine from his experiments?

10. Circle the letter of each sentence that is true about atoms, matter, and electric charge.
    a. All atoms have an electric charge.
    b. Electric charges are carried by particles of matter.
    c. Electric charges always exist in whole-number multiples of a single basic unit.
    d. When a given number of positively charged particles combines with an equal number of negatively charged particles, an electrically neutral particle is formed.

11. Circle the letter next to the number of units of positive charge that remain if a hydrogen atom loses an electron.
    a. 0  b. 1  c. 2  d. 3

12. The positively charged subatomic particle that remains when a hydrogen atom loses an electron is called a(n) _____________________.

13. What charge does a neutron carry? ____________________
14. Complete the table about the properties of subatomic particles.

<table>
<thead>
<tr>
<th>Properties of Subatomic Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particle</strong></td>
</tr>
<tr>
<td>Electron</td>
</tr>
<tr>
<td>Proton</td>
</tr>
<tr>
<td>Neutron</td>
</tr>
</tbody>
</table>

The Atomic Nucleus

15. Is the following sentence true or false? An alpha particle has a double positive charge because it is a helium atom that has lost two electrons. ________________

16. Explain why in 1911 Rutherford and his coworkers were surprised when they shot a narrow beam of alpha particles through a thin sheet of gold foil.

__________________________

__________________________

__________________________

17. Circle the letter of each sentence that is true about the nuclear theory of atoms suggested by Rutherford’s experimental results.

   a. An atom is mostly empty space.
   b. All the positive charge of an atom is concentrated in a small central region called the nucleus.
   c. The nucleus is composed of protons.
   d. The nucleus is large compared with the atom as a whole.
   e. Nearly all the mass of an atom is in its nucleus.

4.3 Distinguishing Among Atoms

**Essential Understanding**  The mass number and number of protons define the type of atom.

Lesson Summary

**Atomic Number and Mass Number** Atomic number and mass number can be used to determine the number of protons and neutrons in an atom.

- Each element has a unique atomic number, which is the number of protons the atom contains.
- Mass number is the total number of protons and neutrons in an atom.
- The number of neutrons in an atom can be found by subtracting the atomic number from the mass number.
**Isotopes** Most elements contain several different isotopes that differ in the number of neutrons they contain.
- Isotopes are atoms of the same element that have different numbers of neutrons.
- Isotopes are chemically alike because they contain the same number of protons and electrons.

**Atomic Mass** The atomic mass of an atom is its actual mass, based on the actual number of each type of subatomic particle it contains.
- The atomic mass of an element is a weighted average of the mass of the isotopes of the element.
- Atomic mass is measured in atomic mass units (amu), which is based on the mass of a carbon-12 atom.
- The atomic mass of an element usually is close to the mass of its most abundant isotope.

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**BUILD Math Skills**

**Percents** A percent is a ratio that compares a number to 100. It’s a shorthand way of expressing a fraction whose denominator is 100. For example, 75% is equivalent to 0.75 or \( \frac{75}{100} \).

One way to calculate percent is to multiply the ratio of the part to the whole by 100%.

\[
\text{percent} = \frac{\text{part}}{\text{whole}} \times 100\%
\]

Because a percent represents a relationship between two quantities, it can be used as a conversion factor. If you know the percent and one variable, you can use dimensional analysis to find the unknown.
Sample Problem Margarete has a monthly salary of $1200. She spends $240 per month on food. What percent of her monthly salary does she spend on food?

List the knowns and unknown.

<table>
<thead>
<tr>
<th>KNOWNS</th>
<th>UNKNOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$240 is the part</td>
<td>percent of monthly salary</td>
</tr>
<tr>
<td>$1200 is the whole</td>
<td></td>
</tr>
</tbody>
</table>

Solve for the unknown.

Start with the formula. \[ \text{percent} = \frac{\text{part}}{\text{whole}} \times 100\% \]

Substitute the numbers in the formula. \[ \text{percent} = \frac{240}{1200} \times 100\% \]

Solve. \[ \text{percent} = \frac{240}{1200} = \frac{1}{5} \times 100\% = 20\% \]

Sample Problem A friend tells you that he got a score of 85% on a test that had 40 questions. How many questions did he answer correctly?

List the knowns and unknown.

<table>
<thead>
<tr>
<th>KNOWNS</th>
<th>UNKNOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>85% correct for every 100 questions</td>
<td>number of correct answers</td>
</tr>
<tr>
<td>40 questions total</td>
<td></td>
</tr>
</tbody>
</table>

Solve for the unknown.

Set up the conversion factor. \[ \frac{40 \text{ questions}}{100} \times \frac{85 \text{ correct}}{100 \text{ questions}} = \frac{3400}{100} = 34 \text{ total correct answers} \]
Now it’s your turn to practice using percents. Answer the following questions.

1. A store discounted a leather jacket by 25%. If the original price was $250, what is the new price of the jacket?

2. A nighttime cold medicine is 22% alcohol (by volume). How many mL of alcohol are in a 250 mL bottle of this cold medicine?

3. Hydrogen peroxide is sold as a 3.0% (by mass) solution. The rest of the solution is water. How many grams of hydrogen peroxide are in 250 g of this solution?

4. A compound is broken down into 34.5 g of element A, 18.2 g of element B, and 2.6 g of element C. What is the percent (by mass) of each element?

After reviewing the part III PowerPoint slides, answer the following questions.

Atomic Number and Mass Number

5. Circle the letter of the term that correctly completes the sentence. Elements are different because their atoms contain different numbers of _________________.
   a. electrons  
   b. protons  
   c. neutrons  
   d. nuclei

6. Complete the table showing the number of protons and electrons in atoms of six elements.

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Atomic number</th>
<th>Number of protons</th>
<th>Number of electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. The total number of protons and neutrons in an atom is its ________________________________.
8. What is the mass number of a helium atom that has two protons and two neutrons?

9. How many neutrons does a beryllium atom with four protons and a mass number of nine have?

10. Place the labels chemical symbol, atomic number, and mass number in the shorthand notation below.

11. Designate the atom shown in Question 10 in the form “name of element”-“mass number.”

12. How many protons, neutrons, and electrons are in the atom discussed in Questions 10 and 11? Protons: Neutrons: Electrons:

Isotopes

13. How do atoms of neon-20 and neon-22 differ?

14. Neon-20 and neon-22 are called ________________.

15. Is the following sentence true or false? Isotopes are chemically alike because they have identical numbers of protons and electrons. ________________

Match the designation of each hydrogen isotope with its commonly used name.

   16. hydrogen-1 a. tritium
   17. hydrogen-2 b. hydrogen
   18. hydrogen-3 c. deuterium

Atomic Mass

19. Why is the atomic mass unit (amu), rather than the gram, usually used to express atomic mass?

20. What isotope of carbon has been chosen as the reference isotope for atomic mass units? What is the defined atomic mass in amu of this isotope?

21. Is the following sentence true or false? The atomic mass of an element is always a whole number of atomic mass units. ________________
22. Circle the letter of each statement that is true about the average atomic mass of an element and the relative abundance of its isotopes.
   a. In nature, most elements occur as a mixture of two or more isotopes.
   b. Isotopes of an element do not have a specific natural percent abundance.
   c. The average atomic mass of an element is usually closest to that of the isotope with the highest natural abundance.
   d. Because hydrogen has three isotopes with atomic masses of about 1 amu, 2 amu, and 3 amu, respectively, the average atomic mass of natural hydrogen is 2 amu.

23. Circle the letter of the correct answer. When chlorine occurs in nature, there are three atoms of chlorine-35 for every one atom of chlorine-37. Which atomic mass number is closer to the average atomic mass of chlorine?
   a. 35 amu
   b. 37 amu

Guided Practice Problems

Answer the following questions about Practice Problem 19.

Use Table 4.2 to express the compositions of carbon-12, fluorine-19, and beryllium-9 in shorthand form.

Carbon-12

Analyse

Step 1. The number of protons in an atom is called its _______________ number. The number of protons in an atom of carbon-12 is _______________.

Calculate

Step 2. The number of protons plus the number of neutrons in an atom is called its _______________ number. For carbon-12, this number is _______________.

Step 3. The shorthand notation for carbon-12 is:

[Diagram: C with mass number and atomic number indicated]
Evaluate

Step 4. Except for hydrogen-1, the mass number of an isotope is always greater than its atomic number. Is the mass number reasonable?

Fluorine-19

Step 1. The atomic number of fluorine-19 is ________________.
Step 2. Its mass number is ________________.
Step 3. The shorthand notation for fluorine-19 is: 

\[
\begin{align*}
&F \\
&\quad \\
&\quad \\
\end{align*}
\]

Step 4. Is your answer reasonable? Why?

_____________________________________________________________________

_____________________________________________________________________

Beryllium-9

Step 1. The atomic number of beryllium-9 is ________________.
Step 2. Its mass number is ________________.
Step 3. The shorthand notation for beryllium-9 is: 

\[
\begin{align*}
&\text{Be} \\
&\quad \\
&\quad \\
\end{align*}
\]

Step 4. Is your answer reasonable? Why?

_____________________________________________________________________

_____________________________________________________________________

Apply the Big idea

A student knows the atomic number and the atomic mass for several different elements. He organized this information in the following table. For these elements, the mass number of the most common isotope is closest to the atomic mass of the element.

a. How do you determine the number of electrons, protons, and neutrons in one atom of the most common isotope from this information?

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

b. Complete the table for a sample of each element.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
<th>Most Common Isotopes</th>
<th>Atomic Mass</th>
<th>Mass Number (of most common isotope)</th>
<th>Number of (in one atom of the most common isotope):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>46Ti, 47Ti, 48Ti, 49Ti, 50Ti</td>
<td>47.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>20</td>
<td>40Ca, 42Ca, 44Ca</td>
<td>40.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tantalum</td>
<td>73</td>
<td>180Ta, 181Ta</td>
<td>180.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Self-Check Activity

For Questions 1–9, complete each statement by writing the correct word or words. If you need help, you can go online.

4.1 Defining the Atom

1. ___________________________ first proposed that atoms are small, indestructible particles that make up all matter.

2. ___________________________ used experimental methods to propose an atomic theory based on earlier ideas.

3. Although atoms are extremely small, scientists can observe them using instruments such as the ___________________________.

4.2 Structure of the Nuclear Atom

4. The particles that make up atoms—protons, neutrons, and electrons—are known as ___________________________ particles.

5. There is a small core known as a(n) ___________________________ in the center of an atom which contains the protons and neutrons.

6. Most of the volume of an atom is occupied by ___________________________.

4.3 Distinguishing Among Atoms

7. The identity of an element is determined by the number of ___________________________ it contains.
8. Each of an element’s __________________ has a different number of neutrons and a different mass number.

9. The __________________ of an element is the weighted average of all the isotopes of the element.

Review Key Equations

For each problem, write the key equation you would use to solve it. Then solve the problem.

1. How many neutrons are in an atom with atomic number of 53 and mass number of 127?

2. In a sample of silver, 51.84% of the atoms have a mass of 106.905 amu and 48.16% have a mass of 108.905 amu. What is the atomic mass of silver?

EXTENSION Explain how you would estimate the answer to Problem 2.

Review Vocabulary

Complete each sentence with a vocabulary term.

The center of a certain atom contains 5 positively charged particles. It also contains 11 other particles.

1. The center of this atom is called the __________.

2. The atom contains 5 __________ and 5 ______________.

3. The atom contains 6 __________.

4. The __________ of the atom is 5.

5. The __________ of the atom is 16.

6. The __________ of a sample of the element is 10.81 _____________.

This number is not a whole number because the sample contains different ______________ of the element.