What Is Inside an Atom?

Democritus and John Dalton thought that atoms could not be divided into smaller parts. J. J. Thomson and Ernest Rutherford discovered that atoms are not indivisible, but contain electrons and nuclei. Later, other scientists discovered that the nucleus of an atom contains smaller particles called protons and neutrons. Each of these subatomic particles—protons, neutrons, and electrons—has different properties, as shown in the table below.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Charge</th>
<th>Mass (kg)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>+1</td>
<td>$1.67 \times 10^{-27}$</td>
<td>inside the nucleus</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
<td>$1.67 \times 10^{-27}$</td>
<td>inside the nucleus</td>
</tr>
<tr>
<td>Electron</td>
<td>-1</td>
<td>$9.11 \times 10^{-31}$</td>
<td>outside the nucleus</td>
</tr>
</tbody>
</table>

As you can see from the table, the nucleus of an atom contains protons and neutrons. Protons have a positive charge. Neutrons do not have a charge. Protons and neutrons are almost identical in size and mass.

Outside the nucleus is a cloud of negatively charged electrons. Electrons have a negative charge. The mass of an electron is much smaller than the mass of a proton or a neutron.

What Do Atoms of the Same Element Have in Common?

All of the atoms of a given element have one thing in common: they have the same number of protons. In fact, you can use the number of protons in an atom to determine which element the atom comes from. For example, all atoms with one proton are atoms of the element hydrogen. Atoms with two protons are helium atoms, as shown in the figure at the top of the next page.
**LOOKING CLOSER**

3. **Infer** The nucleus of a helium atom contains four subatomic particles. How many neutrons does the helium atom have?

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**BALANCING CHARGE WITH ELECTRONS**

Protons and electrons have electric charges. However, atoms are neutral—that is, they do not have an electric charge. The reason for this is that atoms have the same number of electrons as protons. The negative charges of the electrons cancel out the positive charges of the protons. (Remember that neutrons, which are also found in atoms, have no electric charge.)

For example, a helium atom contains two protons in its nucleus. Therefore, the nucleus of a helium atom has a charge of $+2$. However, a helium atom also has two electrons. The electrons have a charge of $-2$. The $-2$ charge of the electrons balances out the $+2$ charge of the nucleus. As a result, the helium atom is neutral.

Sometimes, atoms can gain or lose electrons. When this happens, an ion forms. An ion is an atom that has gained or lost electrons and thus has an electric charge.

**THE ELECTRIC FORCE**

Positive and negative charges attract each other with a force called the electric force. The negatively charged electrons and the positively charged protons in an atom attract each other with the electric force. In fact, this force is what holds atoms together.

**What Is an Atomic Number?**

All atoms of an element have the same number of protons. This number is called the atomic number ($Z$) of the element. Neutral atoms have the same number of electrons as protons. Therefore, the atomic number of an element equals the number of electrons in an atom of the element.
ATOMIC NUMBER AND PROTONS

Each element has a unique number of protons. Therefore, each element has its own unique atomic number. All atoms of a given element have the same atomic number. For example, hydrogen only has one proton, so its atomic number is 1. Uranium has 92 protons. Therefore, its atomic number is 92. The number of protons in an atom is equal to the atom’s atomic number.

MASS NUMBER

The nuclei of most atoms contain both protons and neutrons. The mass number (A) of an element equals the number of protons plus the number of neutrons. All atoms of an element have the same number of protons. However, atoms of the same element can have different numbers of neutrons. Therefore, atoms of the same element always have the same atomic number, but can have different mass numbers.

ISOTOPES

Atoms of a single element can have different numbers of neutrons. Atoms of an element with different numbers of neutrons are called isotopes. Isotopes contain the same number of protons as all atoms of an element. Therefore, they have the same atomic number. However, because isotopes have different numbers of neutrons, they have different mass numbers.

Look at the figure below. The figure shows three isotopes of hydrogen. Each hydrogen isotope has an atomic number of 1 because it contains one proton. However, each isotope has a different number of neutrons. Therefore, each isotope has a different mass number.

Isotopes of Hydrogen

- Protium: A = 1, Z = 1
- Deuterium: A = 2, Z = 1
- Tritium: A = 3, Z = 1

Each isotope of hydrogen has a different number of neutrons. However, all isotopes of hydrogen have the same number of protons.

Critical Thinking

Apply Concepts

Aluminum has an atomic number of 13. How many protons does an atom of aluminum have? How many electrons does it have?

READING CHECK

7. Explain How can atoms of the same element have different mass numbers?

8. Identify How many electrons do all isotopes of hydrogen have?
How Common Are Different Isotopes?

Some isotopes of an element are more common than others. For example, more than 99% of the oxygen atoms on Earth contain 8 protons and 8 neutrons. Only about 0.2% of the oxygen atoms on Earth contain 8 protons and 10 neutrons.

Some isotopes are unstable. These isotopes decay, or break down, over time. Sometimes, when an isotope decays, it forms a different isotope of the same element.

How Can You Show an Atom’s Atomic and Mass Numbers?

You can use chemical symbols to represent atoms of different elements. For example, the symbol Cl represents an atom of the element chlorine. The chemical symbols for all the elements are in the periodic table at the back of this book.

Scientists use numbers placed before the symbol of an element to show an atom’s mass number and atomic number. The mass number is always written above the atomic number, as shown below.

You can also identify an isotope of an element in words. For example, the isotope of uranium with a mass number of 235 can be written “uranium-235.”

You can calculate the number of neutrons in an atom by subtracting the atom’s atomic number from its mass number. For example, an atom of uranium-235 has a mass number of 235. Like all atoms of uranium, it has an atomic number of 92. Therefore, an atom of uranium-235 has $235 - 92 = 143$ neutrons.
ATOMIC MASS

The mass of a single atom is very small. For example, an atom of fluorine has a mass of less than one trillionth of one billionth of one gram. Therefore, scientists use a special unit to describe the masses of atoms. This unit is called a unified atomic mass unit. A unified atomic mass unit (u) is equal to one-twelfth the mass of a carbon-12 atom. This is about the same as the mass of a proton or a neutron.

It can be easy to confuse atomic mass and mass number. Atomic mass is the mass of a single atom of an element. Atomic mass is measured in unified atomic mass units or in grams. Mass number is the sum of the number of protons and neutrons in an atom. Mass number does not have any units, and it is always a whole number.

AVERAGE ATOMIC MASS

The figure below shows the entry in the periodic table for chlorine. The number written above the chemical symbol is the atomic number of chlorine, 17. The number below the chemical symbol is the average atomic mass of chlorine. This number is related to the atomic masses of chlorine atoms.

![Periodic Table Entry for Chlorine]

About 76% of chlorine atoms are chlorine-35 atoms, with atomic masses of about 35 u. About 24% of chlorine atoms are chlorine-37 atoms, with atomic masses of about 37 u. The weighted average of these two numbers gives the average atomic mass of chlorine, 35.453 u.

There are two isotopes of chlorine: chlorine-35 and chlorine-37. However, both isotopes are not equally common in nature. If you could collect 100 atoms of chlorine, about 24 of them would be chlorine-37 atoms, and about 76 of them would be chlorine-35 atoms. In other words, about 24% of the chlorine atoms on Earth are chlorine-37 atoms. The other 76% are chlorine-35 atoms.

The average atomic mass of chlorine represents the average mass of all the chlorine atoms on Earth. It is a weighted average. That is, because most chlorine atoms are chlorine-35 atoms, the average atomic mass of chlorine is closer to 35 u than to 37 u.
How Can You Convert Atomic Masses to Grams?

Scientists use unified atomic mass units to describe the masses of single atoms. However, in most cases, chemists deal with huge numbers of atoms. For example, 1 g of table sugar contains about \(1.8 \times 10^{21}\) molecules of sugar. It is much easier to use grams to describe the masses of such large numbers of particles.

Chemists use a special unit called a mole to represent large numbers of particles. A **mole** (mol) is the basic unit used to measure the amount of a substance. One mole is equal to a very large number of particles:

\[
1 \text{ mol} = 602,213,670,000,000,000,000,000 \text{ particles}
\]

This number, which is called **Avogadro’s number**, is usually written as \(6.022 \times 10^{23}\). The number is named after the Italian scientist Amedeo Avogadro.

Why is \(6.022 \times 10^{23}\) the number of particles in one mole? Chemists have defined a mole as the number of atoms in 12.00 g of carbon-12. From experiments, we know that there are \(6.022 \times 10^{23}\) atoms in 12.00 g of carbon-12.

**Molar Mass**

The mass of one mole of a substance is called its **molar mass**. For example, 1 mol of carbon-12 atoms has a mass of 12 grams. Therefore, the molar mass of carbon-12 is 12.00 g/mol. One mole of table sugar has a mass of 342.3 g. Therefore, the molar mass of table sugar is 342.3 g/mol.

You can use the mole to convert the average atomic masses on the periodic table into grams. The mass in grams of one mole of any element equals the element’s average atomic mass in unified atomic mass units. An example is shown in the figure below.

### Critical Thinking

**15. Apply Concepts** The molar mass of sodium chloride is 58 g/mol. How many grams of sodium chloride are in 0.5 mol of sodium chloride?

### Reading Check

**14. Define** What is a mole?

**15. Apply Concepts** The molar mass of sodium chloride is 58 g/mol. How many grams of sodium chloride are in 0.5 mol of sodium chloride?

**16. Identify** What is the molar mass of magnesium? Give your answer with three significant figures.
CONVERTING MOLES TO GRAMS
Let’s look at an example of how to convert between moles and grams. What is the mass in grams of 5.50 mol of iron? Remember that the average atomic mass of each element is listed in the periodic table at the back of this book.

<table>
<thead>
<tr>
<th>Step 1: List the given and unknown values.</th>
<th>Given: amount of iron = 5.50 mol</th>
<th>Unknown: mass of iron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>molar mass of iron = 55.84 g/mol</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 2: Write the conversion factor. The numerator should have the units you are trying to find. The denominator should have the units you are trying to cancel.</th>
<th>conversion factor:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>55.84 g Fe</td>
</tr>
<tr>
<td></td>
<td>1 mol Fe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step 3: Multiply by the conversion factor to solve.</th>
<th>5.50 mol Fe × 55.84 g Fe = 307 g Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 mol Fe</td>
</tr>
</tbody>
</table>

MOLAR MASSES OF COMPOUNDS
Remember that compounds are made of atoms joined together in specific ratios. Because compounds have fixed compositions, they also have molar masses. To find a compound’s molar mass, add the masses of all the atoms in one molecule of the compound. For example, suppose you wanted to find the molar mass of water (H₂O). Follow these steps:

1. Look in the periodic table to find the molar masses of the elements in the compound.
   Water contains oxygen and hydrogen. Oxygen’s molar mass is 16.00 g/mol. (For problems in this book, round all masses in the periodic table to the hundredths place.) Hydrogen’s molar mass is 1.01 g/mol.

2. Use the chemical formula of water to determine how many atoms of each element are in the compound.
   The chemical formula H₂O tells you that each molecule of water contains two hydrogen atoms and one oxygen atom.

3. Add up the masses of all the atoms in the molecule.
   
   \((2) \times (1.01 \text{ g/mol}) + (1) \times (16.00 \text{ g/mol}) = 18.02 \text{ g/mol}\)
   So, the molar mass of water is 18.02 g/mol.

Math Skills
17. Calculate What is the mass in grams of 3.20 mol of copper (Cu)? Show your work.

18. Calculate What is the molar mass of methane, CH₄? Show your work.

Critical Thinking
18. Calculate What is the molar mass of methane, CH₄? Show your work.
Section 2 Review

SECTION VOCABULARY

| atomic number | the smallest unit of an element that maintains the chemical properties of that element |
| isotope       | an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass) |
| mass number   | the sum of the numbers of protons and neutrons in the nucleus of an atom |
| mole          | the SI base unit used to measure the amount of a substance whose number of particles is the same as the number of atoms of carbon in exactly 12 g of carbon-12 |

neutron a subatomic particle that has no charge and that is located in the nucleus of an atom

proton a subatomic particle that has a positive charge and that is located in the nucleus of an atom; the number of protons in the nucleus is the atomic number, which determines the identity of an element

unified atomic mass unit a unit of mass that describes the mass of an atom or molecule; it is exactly 1/12 of the mass of a carbon atom with mass number 12

1. Compare What is the difference between mass number and atomic mass?

2. Apply Concepts Fill in the blank spaces in the table below. Then, use the information in the table to answer questions 3 and 4.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Atomic number</th>
<th>Mass number</th>
<th>Number of neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>13</td>
<td>87</td>
<td>14</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>E</td>
<td>38</td>
<td></td>
<td>49</td>
</tr>
</tbody>
</table>

3. Identify Which two atoms in the table are isotopes of the same element? Explain your answer.

4. Describe How many electrons does atom D contain? Explain your answer.

5. Calculate How many moles of glucose, \( C_6H_{12}O_6 \), are in 300 g of glucose? Show your work.