

10.1 The Mole: A Measurement of Matter

Connecting to Your World

Every year, contestants from all over the world travel to Harrison Hot Springs in British Columbia, Canada, to compete in the world championship sand sculpture contest.



Each contestant creates a beautiful work of art out of millions of tiny grains of sand. You could measure the amount of sand in a sculpture by counting the grains of sand. But wouldn't it be much easier to weigh the sand? In this section, you'll discover how chemists measure the amount of a substance using a unit called a mole.

Measuring Matter

You live in a quantitative world. The grade you got on your last exam, the number of times you heard your favorite song on the radio yesterday, and the cost of a bicycle you would like to own are all important quantities to you. These are quantities that answer questions such as "How much?" or "How many?" Scientists answer similar questions. How many kilograms of iron can be obtained from one hundred kilograms of iron ore? How many grams of hydrogen and nitrogen must be combined to make 200 grams of the fertilizer ammonia (NH_3)? Questions like these illustrate that chemistry is a quantitative science. In your study of chemistry, you will analyze the composition of samples of matter and perform chemical calculations that relate quantities of reactants in a chemical reaction to quantities of products. To solve these and other problems, you will have to be able to measure the amount of matter you have.


How do you measure matter? One way is to count how many of something you have. For example, you can count the CDs in your collection or the number of pins you knock down when bowling. Another way to measure matter is to determine its mass. You can buy potatoes by the kilogram or pound and gold by the gram or ounce. You can also measure matter by volume. For instance, people buy gasoline by the liter or the gallon and take cough medicine by the milliliter or the teaspoon.  **You often measure the amount of something by one of three different methods—by count, by mass, and by volume.** For example, you can buy soda by the six-pack or by the liter. Figure 10.1 shows how you might measure the amount of grapes you want to buy.

Figure 10.1 A grocer's scale measures the weight of the grapes you buy.

Guide for Reading

Key Concepts

- What are three methods for measuring the amount of something?
- How is Avogadro's number related to a mole of any substance?
- How is the atomic mass of an element related to the molar mass of an element?
- How is the mass of a mole of a compound calculated?

Vocabulary

mole
Avogadro's number
representative particle
molar mass

Reading Strategy

Relating Text and Visuals As you read, look closely at Table 10.2. Explain how the information in the table helps you understand the basis for the molar masses of the elements.



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10.1

1 FOCUS

Objectives

- 10.1.1 Describe** methods of measuring the amount of something.
- 10.1.2 Define** Avogadro's number as it relates to a mole of a substance.
- 10.1.3 Distinguish** between the atomic mass of an element and its molar mass.
- 10.1.4 Describe** how the mass of a mole of a compound is calculated.

Guide for Reading

Build Vocabulary

Connect Terms Have students write two or three sentences, each of which relates a mole to one or two of the other vocabulary words. Answers might include the following: A mole contains Avogadro's number of particles. The mass of one mole of a substance is its molar mass, which is found by determining the mass in grams of its representative particle.

Reading Strategy

Visualize Students may more easily grasp the meaning of the mole by developing their own mental picture. For example, by analogy to a dozen, they may visualize a giant egg box with 6.02×10^{23} depressions for particles, or a giant sack bulging with Avogadro's number of particles.

2 INSTRUCT

Connecting to Your World

Ask, **Is it practical to count each grain of sand?** (Students should realize that it is not practical to measure sand by counting individual grains.) **How else might you measure, or quantify, the sand?** (Find its mass or volume.) Lead students to see that just as a small amount of sand contains millions of smaller particles, so also small amounts of chemical substances contain very large numbers of particles.



Section Resources

Print

- **Guided Reading and Study Workbook**, Section 10.1
- **Core Teaching Resources**, Section 10.1 Review
- **Transparencies**, T104–T107

Technology

- **Interactive Textbook with ChemASAP**, Animation 11; Problem-Solving 10.1, 10.4, 10.5, 10.7; Assessment 10.1
- **Go Online**, Section 10.1

Measuring Matter

Relate

L1

Point out to students that they often use conversion factors. If a recipe calls for six eggs, this quantity can be considered half a dozen eggs ($6 \text{ eggs} \times 1 \text{ doz}/12 \text{ eggs}$). Four shoes equal two pairs ($4 \text{ shoes} \times 1 \text{ pair}/2 \text{ shoes}$). The concepts presented in this section involve the use of conversion factors in dimensional analysis or the factor-label method of problem solving. Ask students to write an everyday equality that is also a definition, such as $3 \text{ feet} = 1 \text{ yard}$. Write their equalities on the board. Examples include $60 \text{ min} = 1 \text{ h}$, $12 \text{ in.} = 1 \text{ ft}$, $60 \text{ s} = 1 \text{ min}$, $2.54 \text{ cm} = 1 \text{ in.}$, and $100 \text{ cm} = 1 \text{ m}$. Point out that equalities can be written in either direction, so $60 \text{ min} = 1 \text{ h}$ can be written as $1 \text{ h} = 60 \text{ min}$. Have them use these equalities to write conversion factors. Ask, **How many seconds are in 2.5 hours?** Show students how to use dimensional analysis to solve this problem. (9000 s)

Discuss

L2

Pass around bags, each of which contains a multiple of 12 beans. Ask students how they would go about determining the quantities of beans in the bags. They could count, weigh, or find the volume of the beans. With multiples of 12 beans in each bag, students may be guided to an understanding of how the word “dozen” can be used as a unit for the quantity of beans in each bag.

Some of the units used for measuring indicate a specific number of items. For example, a pair always means two. A pair of shoes is two shoes, and a pair of aces is two aces. Similarly, a dozen always means 12. A dozen eggs is 12 eggs and a dozen pens is 12 pens.

Apples are measured in three different ways. At a fruit stand, they are often sold by the count (3 for \$2.40). In a supermarket, you usually buy apples by weight (\$1.29/pound) or mass (\$2.79/kg). At an orchard, you can buy apples by volume (\$12.00/bushel). Each of these different ways to measure apples can be equated to a dozen apples.

By count: 1 dozen apples = 12 apples

For average-sized apples the following approximations can be used.

By mass: 1 dozen apples = 2.0 kg apples

By volume: 1 dozen apples = 0.20 bushel apples

Figure 10.2 shows other items sold by count, weight, and volume.

Knowing how the count, mass, and volume of apples relate to a dozen apples allows you to convert among these units. For example, based on the unit relationships given above, you could calculate the mass of a bushel of apples or the mass of 90 average-sized apples using conversion factors such as the following.

$$\frac{1 \text{ dozen apples}}{12 \text{ apples}} \quad \frac{2.0 \text{ kg apples}}{1 \text{ dozen apples}} \quad \frac{1 \text{ dozen apples}}{0.20 \text{ bushel apples}}$$

Checkpoint What are three ways of measuring the amount of a substance?



Figure 10.2 You can buy items by different types of measurements, such as a count, a weight or mass, or a volume.

Classifying Which of these common items are being sold by weight? By volume? By count?

Differentiated Instruction

English Learners

L1

For this chapter, team up a limited English proficient student with a student who has strong mathematical skills. Encourage the English learners to ask their partners for help with any difficulty they are having understanding the terms and how to solve the problems.

SAMPLE PROBLEM 10.1

Finding Mass from a Count

What is the mass of 90 average-sized apples if 1 dozen of the apples has a mass of 2.0 kg?



1 Analyze List the knowns and the unknown.

Knowns

- number of apples = 90 apples
- 12 apples = 1 dozen apples
- 1 dozen apples = 2.0 kg apples

Unknown

- mass of 90 apples = ? kg

You can use dimensional analysis to convert the number of apples to the mass of apples. Carry out this conversion by performing the following sequence of conversions:

Number of apples \longrightarrow dozens of apples \longrightarrow mass of apples.

2 Calculate Solve for the unknown.

The first conversion factor is $\frac{1 \text{ dozen apples}}{12 \text{ apples}}$.

The second conversion factor is $\frac{2.0 \text{ kg apples}}{1 \text{ dozen apples}}$.

Multiplying the original number of apples by these two conversion factors gives the answer in kilograms.

$$\begin{aligned} \text{mass of apples} &= 90 \text{ apples} \times \frac{1 \text{ dozen apples}}{12 \text{ apples}} \times \frac{2.0 \text{ kg apples}}{1 \text{ dozen apples}} \\ &= 15 \text{ kg apples} \end{aligned}$$

The mass of 90 average-sized apples is 15 kg.

3 Evaluate Does the result make sense?

Because a dozen apples has a mass of 2.0 kg, and 90 apples is less than 10 dozen apples, the mass should be less than 20 kg of apples (10 dozen \times 2.0 kg/dozen).

Practice Problems

1. If 0.20 bushel is 1 dozen apples and a dozen apples has a mass of 2.0 kg, what is the mass of 0.50 bushel of apples?
2. Assume 2.0 kg of apples is 1 dozen and that each apple has 8 seeds. How many apple seeds are in 14 kg of apples?

CHEMath

Dimensional Analysis

Dimensional analysis is a tool for solving conversion problems—problems in which a measurement must be expressed in a different unit.

To solve a simple one-step conversion problem (for example, How many grams is 34 kg?), you must know the relationship between the unit of the known measurement (kg) and the unit of the desired answer (g). The relationship is: 1 kg = 1000 g.

Write this equality as a ratio (conversion factor). When you multiply the known measurement by the conversion factor, the unit kg cancels and the resulting answer has the unit g.

In more complex problems, you may need to use more than one conversion factor to obtain the answer, but the principle is the same.

Math Handbook

For help with dimensional analysis, go to page R66.

Interactive Textbook

Problem-Solving 10.1
Solve Problem 1 with the help of an interactive guided tutorial.

with ChemASAP

Sample Problem 10.1

Answers

1. 0.50 bushel \times 1 dozen/0.20 bushel \times 2.0 kg/1 dozen = 5.0 kg
2. 14 kg \times 1 dozen/2.0 kg \times 12 apples/1 dozen \times 8 seeds/1 apple = 672 seeds

Practice Problems Plus

L2

How many bushels of apples are in 1.0 kg of apples? (0.10 bushels)

CHEMath

Dimensional Analysis

Dimensional analysis uses conversion factors, which are ratios equal to one. Units that can be related by conversion factors can be changed from one unit to another. Chemistry problems involving dimensional analysis range from simple, one-factor conversions, such as changing m to cm, to problems that involve several conversion factors, such as changing a number of atoms to the mass of moles.

Math Handbook

For a math refresher and practice, direct students to dimensional analysis, page R66.

Differentiated Instruction

Special Needs

L1

Some students may experience difficulty with using dimensional analysis and should be given additional simple conversion problems for practice before they start doing problems involving the mole. Review the use of parentheses and the fraction bar as ways of grouping symbols to indicate the order of operations. Stress the importance of labels.

Answers to...

Figure 10.2 Weight, bird seed and screws; volume, paint; count, paint brush

Checkpoint by count, by mass, and by volume

What is a Mole?

Use Visuals

L1

Figure 10.3 Have students study Figure 10.3 and read the text that discusses the number of particles in a mole. Point out that the mole represents a number of items just as *dozen*, *gross*, and *ream* all represent a number of items. Ask, **If you are counting the number of an extremely small item, should the number of items in a unit be small or large?** (For a small item, a large number per counting unit is more convenient.) A mole = 6.02×10^{23} items and is used to measure extremely small objects.

Relate

L2

Students usually need to review scientific notation and multiplication and division of exponents. Write several large and small numbers on the board using standard notation. Have students rewrite the numbers using scientific notation. Ask, **What are some measurements that should be written in scientific notation?** (Students may mention extremely large or extremely small numbers such as the diameter of a virus or distances in space.)



Figure 10.3 Words other than *mole* are used to describe a number of something—for example, a *ream* of paper (500 sheets), a *gross* of pencils (144), and a *dozen* eggs (12).

What Is a Mole?

Counting objects as big as apples is a reasonable way to measure the amount of apples. But imagine trying to count the grains of sand in a sand sculpture. That would be an endless job. Recall that matter is composed of atoms, molecules, and ions. These particles are much smaller than grains of sand and an extremely large number of them are in even a small sample of a substance. Obviously, counting particles one by one is not practical. However, think about counting eggs. It's easier when the eggs are grouped into dozens. A dozen is a specified number, 12, of things. Other common groupings of items are shown in Figure 10.3. Chemists also use a unit that is a specified number of particles. The unit is called a mole. Just as a dozen eggs is 12 eggs, a **mole** (mol) of a substance is 6.02×10^{23} representative particles of that substance and is the SI unit for measuring the amount of a substance. The number of representative particles in a mole, 6.02×10^{23} , is called **Avogadro's number**. It was named in honor of the Italian scientist Amedeo Avogadro di Quaregna (1776–1856) who helped clarify the difference between atoms and molecules.

The term **representative particle** refers to the species present in a substance: usually atoms, molecules, or formula units. The representative particle of most elements is the atom. Iron is composed of iron atoms. Helium is composed of helium atoms. Seven elements, however, normally exist as diatomic molecules (H_2 , N_2 , O_2 , F_2 , Cl_2 , Br_2 , and I_2). The representative particle of these elements and of all molecular compounds is the molecule. The molecular compounds water (H_2O) and sulfur dioxide (SO_2) are composed of H_2O and SO_2 molecules, respectively. For ionic compounds, such as calcium chloride, the representative particle is the formula unit $CaCl_2$.

➡ A mole of any substance contains Avogadro's number of representative particles, or 6.02×10^{23} representative particles. Table 10.1 summarizes the relationship between representative particles and moles of substances.

Converting Number of Particles to Moles The relationship, $1 \text{ mol} = 6.02 \times 10^{23}$ representative particles, is the basis for a conversion factor that you can use to convert numbers of representative particles to moles.

$$\text{moles} = \text{representative particles} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ representative particles}}$$

✓ Checkpoint How many representative particles are in one mole?

Table 10.1

Representative Particles and Moles

Substance	Representative particle	Chemical formula	Representative particles in 1.00 mole
Atomic nitrogen	Atom	N	6.02×10^{23}
Nitrogen gas	Molecule	N_2	6.02×10^{23}
Water	Molecule	H_2O	6.02×10^{23}
Calcium ion	Ion	Ca^{2+}	6.02×10^{23}
Calcium fluoride	Formula unit	CaF_2	6.02×10^{23}
Sucrose	Molecule	$C_{12}H_{22}O_{11}$	6.02×10^{23}



Differentiated Instruction

Gifted and Talented

L3

Gifted students may wish to investigate different methods for determining Avogadro's number. They could present their findings to the class.



Download a worksheet on the **Mole** for students to complete, and find additional teacher support from NSTA SciLinks.

SAMPLE PROBLEM 10.2

Converting Number of Atoms to Moles

Magnesium is a light metal used in the manufacture of aircraft, automobile wheels, tools, and garden furniture. How many moles of magnesium is 1.25×10^{23} atoms of magnesium?

1 Analyze List the knowns and the unknown.

Knowns

- number of atoms = 1.25×10^{23} atoms Mg
- $1 \text{ mol Mg} = 6.02 \times 10^{23}$ atoms Mg
- The desired conversion is: atoms \longrightarrow moles

Unknown

- moles = ? mol Mg

2 Calculate Solve for the unknown.

The conversion factor is $\frac{1 \text{ mol Mg}}{6.02 \times 10^{23} \text{ atoms Mg}}$.

Multiplying atoms of Mg by the conversion factor gives the answer.

$$\text{moles} = 1.25 \times 10^{23} \text{ atoms Mg} \times \frac{1 \text{ mol Mg}}{6.02 \times 10^{23} \text{ atoms Mg}}$$

$$\text{moles} = 2.08 \times 10^{-1} \text{ mol Mg} = 0.208 \text{ mol Mg}$$

3 Evaluate Does the result make sense?

Because the given number of atoms is less than one-fourth of Avogadro's number, the answer should be less than one-fourth mole of atoms. The answer should have three significant figures.

Practice Problems

3. How many moles is 2.80×10^{24} atoms of silicon?
4. How many moles is 2.17×10^{23} representative particles of bromine?

Converting Moles to Number of Particles Now suppose you want to determine how many atoms are in a mole of a compound. To do this, you must know how many atoms are in a representative particle of the compound. This number is determined from the chemical formula. Figure 10.4 illustrates this idea with marbles (atoms) in cups (molecules). The number of marbles in a dozen cups is (6×12) , or 72 marbles. In the formula of a molecule of carbon dioxide (CO_2), the subscripts show that carbon dioxide is composed of three atoms: one carbon atom and two oxygen atoms. A mole of carbon dioxide contains Avogadro's number of CO_2 molecules. But each molecule contains three atoms. Thus a mole of carbon dioxide contains three times Avogadro's number of atoms. A molecule of carbon monoxide (CO) consists of two atoms, so a mole of carbon monoxide contains two times Avogadro's number of atoms.

Figure 10.4 A dozen cups of marbles contain more than a dozen marbles. Similarly, a mole of molecules contains more than a mole of atoms. **Calculating** How many atoms are in one mole of molecules if each molecule consists of six atoms?



Use Visuals

L1

Figure 10.4 Have students examine the photograph. Note that each cup contains six marbles. A dozen cups hold 72 marbles. Ask, **What are some everyday items that come in a “package” of more than one?** (*gum, 5 sticks; shoes, 2; batteries, 2, 4, 8*) Point out that a dozen packages of gum would be five dozen sticks of gum or 60 sticks of gum. Point out that this idea can be applied to molecules. For example, a mole of water (H_2O) consists of 2 mol H atoms and 1 mol O atoms. Thus a mole of water contains $3 \times 6.02 \times 10^{23}$ atoms or 1.8×10^{24} atoms.

Sample Problem 10.2

Answers

3. 2.80×10^{24} atoms Si $\times 1 \text{ mol}/6.02 \times 10^{23}$ atoms = 4.65 mol Si
4. 2.17×10^{23} representative particles $\times 1 \text{ mol}/6.02 \times 10^{23}$ representative particles = 0.360 mol Br_2

Practice Problems Plus

L2

1. How many moles are equal to 2.41×10^{24} formula units of sodium chloride (NaCl)? (4.00 moles)
2. How many moles are equal to 9.03×10^{24} atoms of mercury (Hg)? (15.0 moles)

Math

Handbook

For a math refresher and practice, direct students to dimensional analysis, page R66.

Answers to...

Figure 10.4 3.61×10^{24} atoms

 **Checkpoint** 6.02×10^{23} representative particles

Section 10.1 (continued)

Sample Problem 10.3

Answers

- $1.14 \text{ mol} \times 6.02 \times 10^{23} \text{ molecules/mol} \times 4 \text{ atoms/molecule} = 2.75 \times 10^{24} \text{ atoms}$
- $4.65 \times 10^{24} \text{ molecules NO}_2 \times 1 \text{ mol}/6.02 \times 10^{23} \text{ molecules} = 7.72 \text{ mol NO}_2$

Practice Problems Plus

L2

- How many atoms are in 1.00 mole of sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$? (2.71×10^{25} atoms)
- How many atoms of C are in 2.00 moles of $\text{C}_{12}\text{H}_{22}\text{O}_{11}$? (1.44×10^{25} atoms)
- How many atoms of H are in 2.00 moles of $\text{C}_{12}\text{H}_{22}\text{O}_{11}$? (2.65×10^{25} atoms)
- How many atoms of O are in 3.65 moles of $\text{C}_{12}\text{H}_{22}\text{O}_{11}$? (2.42×10^{25} atoms)

Math

Handbook

For a math refresher and practice, direct students to dimensional analysis, page R66.



Math Handbook

For help with dimensional analysis, go to page R66.

Interactive Textbook

Problem-Solving 10.5
Solve Problem 5 with the help of an interactive guided tutorial.

with ChemASAP

To find the number of atoms in a mole of a compound, you must first determine the number of representative particles. You can use the following conversion factor to convert a number of moles of a compound to the number of representative particles (molecules or formula units).

$$\text{representative particles} = \text{moles} \times \frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ mole}}$$

The next step is to multiply the number of representative particles by the number of atoms in each molecule or formula unit.

SAMPLE PROBLEM 10.3

Converting Moles to Number of Atoms

Propane is a gas used for cooking and heating. How many atoms are in 2.12 mol of propane (C_3H_8)?

1 Analyze List the knowns and the unknown.

Knowns

- number of moles = 2.12 mol C_3H_8
- 1 mol $\text{C}_3\text{H}_8 = 6.02 \times 10^{23}$ molecules C_3H_8
- 1 molecule $\text{C}_3\text{H}_8 = 11$ atoms
(3 carbon atoms and 8 hydrogen atoms)
- The desired conversion is: moles \longrightarrow molecules \longrightarrow atoms.

Unknown

- number of atoms = ? atoms

Use the relationships among units given above to write the desired conversion factors.

2 Calculate Solve for the unknown.

The first conversion factor is $\frac{6.02 \times 10^{23} \text{ molecules } \text{C}_3\text{H}_8}{1 \text{ mol } \text{C}_3\text{H}_8}$.

The second conversion factor is $\frac{11 \text{ atoms}}{1 \text{ molecule } \text{C}_3\text{H}_8}$.

Multiply the moles of C_3H_8 by the proper conversion factors:

$$2.12 \text{ mol } \text{C}_3\text{H}_8 \times \frac{6.02 \times 10^{23} \text{ molecules } \text{C}_3\text{H}_8}{1 \text{ mol } \text{C}_3\text{H}_8} \times \frac{11 \text{ atoms}}{1 \text{ molecule } \text{C}_3\text{H}_8} = 1.4039 \times 10^{25} \text{ atoms} = 1.40 \times 10^{25} \text{ atoms}$$

3 Evaluate Does the result make sense?

Because there are 11 atoms in each molecule of propane and more than 2 mol of propane, the answer should be more than 20 times Avogadro's number of propane molecules. The answer has three significant figures based on the three significant figures in the given measurement.

Practice Problems

- How many atoms are in 1.14 mol SO_3 ?
- How many moles are in 4.65×10^{24} molecules of NO_2 ?

Differentiated Instruction

Special Needs

L1

Some students may experience difficulty with mathematical concepts. To help these students learn to do the many calculations in this chapter, have them write out, in their own words, a step-by-step procedure for doing each of the sample problems. Suggest that they ask a study partner to read their procedures and correct them, if necessary.

Perhaps you are wondering just how large a mole is. The SI unit, the mole, is not related to the small burrowing animal of the same name shown in Figure 10.5. But this little animal can help you appreciate the size of the number 6.02×10^{23} . Assume that an average animal-mole is 15 cm long, 5 cm tall, and has a mass of 150 g. Based on this information, the mass of 6.02×10^{23} animal-moles is 9.03×10^{22} kg. That means that the mass of Avogadro's number of animal-moles is equal to more than 60 times the combined mass of Earth's oceans. If spread over the entire surface of Earth, Avogadro's number of animal-moles would form a layer more than 8 million animal-moles thick. What about the length of 6.02×10^{23} animal-moles? If lined up end-to-end, 6.02×10^{23} animal-moles would stretch from Earth to the nearest star, Alpha Centauri, more than two million times. Are you beginning to understand how enormous Avogadro's number is?



Figure 10.5 An average animal-mole has a mass of 150 g. The mass of 6.02×10^{23} animal-moles is 9.03×10^{22} kg.

The Mass of a Mole of an Element







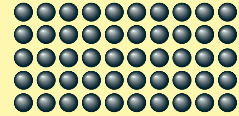

Remember that the atomic mass of an element (the mass of a single atom) is expressed in atomic mass units (amu). The atomic masses are relative values based on the mass of the most common isotope of carbon (carbon-12). Table 10.2 shows that an average carbon atom (C) with an atomic mass of 12.0 amu is 12 times heavier than an average hydrogen atom (H) with an atomic mass of 1.0 amu. Therefore, 100 carbon atoms are 12 times heavier than 100 hydrogen atoms. In fact, any number of carbon atoms is 12 times heavier than the same number of hydrogen atoms. The mass ratio of 12 carbon atoms to 1 hydrogen atom remains the same no matter what unit is used to express the masses. So 12.0 g of carbon atoms and 1.0 g of hydrogen atoms must contain the same number of atoms.

Interactive Textbook

Animation 11 Find out how Avogadro's number is based on the relationship between the amu and the gram.

with ChemASAP

Table 10.2

CARBON ATOMS		HYDROGEN ATOMS		MASS RATIO
Number	Mass (amu)	Number	Mass (amu)	Mass carbon Mass hydrogen
	12		1	$\frac{12 \text{ amu}}{1 \text{ amu}} = \frac{12}{1}$
	24 [2 × 12]		2 [2 × 1]	$\frac{24 \text{ amu}}{2 \text{ amu}} = \frac{12}{1}$
	120 [10 × 12]		10 [10 × 1]	$\frac{120 \text{ amu}}{10 \text{ amu}} = \frac{12}{1}$
	600 [50 × 12]		50 [50 × 1]	$\frac{600 \text{ amu}}{50 \text{ amu}} = \frac{12}{1}$
Avogadro's number	$(6.02 \times 10^{23}) \times (12)$	Avogadro's number	$(6.02 \times 10^{23}) \times (1)$	$\frac{(6.02 \times 10^{23}) \times (12)}{(6.02 \times 10^{23}) \times (1)} = \frac{12}{1}$

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The Mass of a Mole of an Element

Discuss

L2

Point out to students that the mass of a single atom can be expressed in atomic mass units, but it is not realistic to work with single atoms. Chemists work with large numbers of atoms for which the mass can be expressed in grams. In this text, the atomic masses are rounded to one place after the decimal point. Have students solve a given problem multiple times using a different rounding rule each time so they can see how rounding the atomic masses affects the answer.

Explain that the molar masses of all elements contain the same number of atoms because the atomic masses of the elements are relative values.

Present this idea by telling the class that the mass of an atom of element X is twice as great as the mass of an atom of element Y. Ask, **If you have 10 grams of element X and 10 grams of element Y, would you expect both samples to contain the same number of atoms?** (No, because atoms of element X are twice as massive as atoms of element Y. The sample of X would contain only half as many atoms as the sample of Y.)

What would you have to do to get the same number of atoms in both samples? (Double the mass of element X to twice the mass of element Y.)

Facts and Figures

History of Avogadro's Number

Avogadro's number was not developed by Avogadro. In the early 1900s, J. Perrin, a French scientist, first used the term "Avogadro's number" to describe the number of particles in a mole. Perrin used Brownian motion to determine the number.

TEACHER Demo

Moles and Mass

L2

Purpose Students observe the difference in the mass and volume of 1 mol of different substances.

Materials 1 mol each of a variety of common chemicals, 1 sealed container per sample

Procedure Place 1 mol of at least two substances from each of the following categories in containers and seal them: molecular compounds—sucrose, water, paradichlorobenzene; ionic compounds—cobalt(II) chloride, potassium hydroxide, potassium dichromate; elements—sulfur, iron, carbon, mercury. On each container, mark the mass of each substance. Point out that each container holds 1 mol of a substance, no matter whether the representative particles are molecules, formula units, or atoms.

Expected Outcome Students observe that a mole of one substance has a different mass from a mole of another substance even though the same number of representative particles (6.02×10^{23}) are present.

Use Visuals

L1

Figure 10.6 Have students study the illustration and verify the stated values for molar masses by looking up the values for the atomic masses in the periodic table. Point out that the molar mass of an element is numerically equal to the atomic mass. Prepare a similar display of other elements in labeled containers for students to view. Ask students to write equations like those in Figure 10.6 for each of the elements displayed.

Go Online
NSTA SciLinks
For: Links on Molar Mass
Visit: www.SciLinks.org
Web Code: cdm-1104

If you look at the atomic masses of the elements in the periodic table, you will notice that they are not whole numbers. For example, the atomic mass of carbon is not exactly 12 times the mass of hydrogen. Recall from Chapter 4 that this is because atomic masses are weighted average masses of the isotopes of each element.

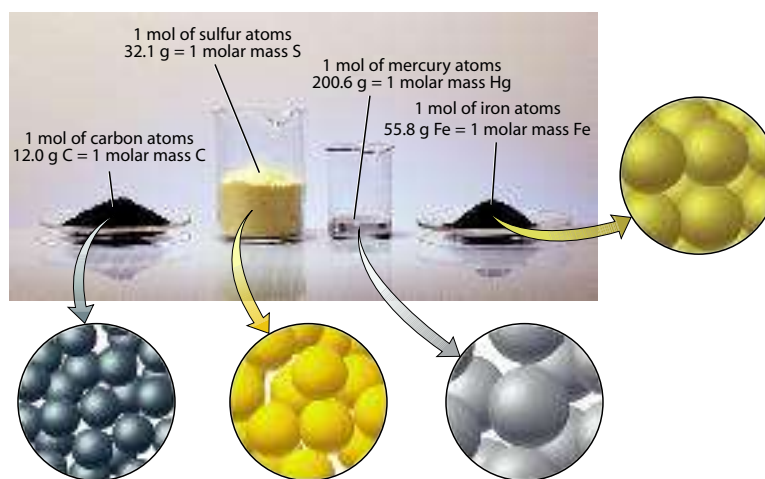
Quantities measured in grams are convenient for working in the laboratory, so chemists have converted the relative scale of masses of the elements in amu to a relative scale of masses in grams. **The atomic mass of an element expressed in grams is the mass of a mole of the element.** The mass of a mole of an element is its **molar mass**. For carbon, the molar mass is 12.0 g. For atomic hydrogen, the molar mass is 1.0 g. Figure 10.6 shows one molar mass of mercury, carbon, iron, and sulfur. Compare the molar masses in the figure to the atomic masses in your periodic table. Notice that the molar masses were rounded off to one place after the decimal point. All the examples and problems in this text use molar masses that are rounded off in this way. If your teacher uses a different rounding rule for molar masses, your answers to problems may differ slightly from the answers given in the text.

If you were to compare 12.0 g of carbon atoms with 16.0 g of oxygen atoms, you would find they contain the same number of atoms. The molar masses of any two elements must contain the same number of atoms. How many atoms are contained in the molar mass of an element? You already know. The molar mass of any element contains 1 mol or 6.02×10^{23} atoms of that element.

The mole can now be further defined as the amount of substance that contains as many representative particles as the number of atoms in 12.0 g of carbon-12. You know that 12.0 g is the molar mass of carbon-12, so 12.0 g is 1 mol of carbon. The same relationship applies to hydrogen: 1.0 g of hydrogen is 1 mol of hydrogen atoms. Similarly, because 24.3 g is the molar mass of magnesium, 1 mol of magnesium (or 6.02×10^{23} atoms of magnesium) has a mass of 24.3 g. Molar mass is the mass of 1 mol of atoms of any element.

Figure 10.6 One molar mass of carbon, sulfur, mercury, and iron are shown. Each of the quantities contains one mole of the element. **Applying Concepts** How many atoms of each element are shown?

Checkpoint How many atoms are in one mole of magnesium?



294 Chapter 10

Differentiated Instruction

Special Needs

L1

For the Teacher Demo, mark the levels of the filled containers with tape on the outside of the containers so that sight-impaired students can tell by handling the displays that moles of different substances occupy different volumes and have different masses.

Go Online
NSTA SciLinks

Download a worksheet on **Molar Mass** for students to complete, and find additional teacher support from NSTA SciLinks.

The Mass of a Mole of a Compound

CLASS Activity

Calculating Molar Mass

L2

Purpose Students learn to calculate the molar mass of a compound.

Materials the display prepared for the Teacher Demo on p. 294

Procedure Select a compound and show students how to calculate the mass of 1 mol using the atomic masses of the constituent elements from the periodic table. Have them calculate the molar masses of other compounds in the display. Point out that they have determined the mass of 6.02×10^{23} representative particles.

ASSESS

Evaluate Understanding

L2

Ask, **What does a mole of a substance represent?** (6.02×10^{23} representative particles of that substance) **How can you convert the number of atoms or molecules of a substance to moles?** (Multiply the number of atoms or molecules by the conversion factor 1 mole/ 6.02×10^{23} representative particles.) **What is the molar mass of $\text{Al}_2(\text{CO}_3)_3$?** (234.0 g)

Reteach

L1

Set up cooperative learning groups of three or four students with one student in each group who can help. Provide the groups with problems related to Section 10.1.



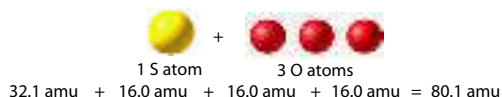
Figure 10.7 One molar mass is shown for each of three molecular compounds. **Inferring** How can you know that each sample contains Avogadro's number of molecules?

The Mass of a Mole of a Compound

To find the mass of a mole of a compound, you must know the formula of the compound. The formula of sulfur trioxide is SO_3 . A molecule of SO_3 is composed of one atom of sulfur and three atoms of oxygen.



You can calculate the mass of a molecule of SO_3 by adding the atomic masses of the atoms making up the molecule. From the periodic table, the atomic mass of sulfur (S) is 32.1 amu. The mass of three atoms of oxygen is three times the atomic mass of a single oxygen atom (O): $3 \times 16.0 \text{ amu} = 48.0 \text{ amu}$. So, the molecular mass of SO_3 is $32.1 \text{ amu} + 48.0 \text{ amu} = 80.1 \text{ amu}$.



Now substitute the unit grams for atomic mass units to find the molar mass of SO_3 . The molar mass (g/mol) of any compound is the mass in grams of 1 mol of that compound. Thus 1 mol of SO_3 has a mass of 80.1 g. This is the mass of 6.02×10^{23} molecules of SO_3 .

To calculate the molar mass of a compound, find the number of grams of each element in one mole of the compound. Then add the masses of the elements in the compound. This method for calculating molar mass applies to any compound, molecular or ionic. The molar masses of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$, 180.0 g), water (H_2O , 18.0 g), and paradichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$, 147.0 g) in Figure 10.7 were obtained in this way.

Section 10.1 The Mole: A Measurement of Matter 295

Differentiated Instruction

English Learners

The differences in the terms *mass*, *atomic mass*, *atomic mass unit*, and *molar mass* may be confusing to English learners. Have students compile a glossary in which they define each term in English and in their native lan-

L2

guage. Encourage students to include an example beside each definition. Before compiling their glossaries, students should be able to use the periodic table and calculate the mass of a mole of any substance.

Answers to...

Figure 10.6 6.02×10^{23} atoms

Figure 10.7 The molar mass is the mass of Avogadro's number of molecules.



Checkpoint 6.02×10^{23} atoms

Section 10.1 (continued)

Sample Problem 10.4

Answers

7. $1 \text{ mol P} \times 31.0 \text{ g P}/1 \text{ mol P} = 31.0 \text{ g P}$
 $3 \text{ mol Cl} \times 35.5 \text{ g Cl}/1 \text{ mol Cl} = 106.5 \text{ g Cl}$
 $31.0 \text{ g P} + 106.5 \text{ g Cl} = 137.5 \text{ g/mol}$
8. $1 \text{ mol Na} \times 23.0 \text{ g Na}/1 \text{ mol Na} = 23.0 \text{ g Na}$
 $1 \text{ mol H} \times 1.0 \text{ g H}/1 \text{ mol H} = 1.0 \text{ g H}$
 $1 \text{ mol C} \times 12.0 \text{ g C}/1 \text{ mol C} = 12.0 \text{ g C}$
 $3 \text{ mol O} \times 16.0 \text{ g O}/1 \text{ mol O} = 48.0 \text{ g O}$
 $23.0 \text{ g Na} + 1.0 \text{ g H} + 12.0 \text{ g C} + 48.0 \text{ g O} = 84.0 \text{ g}$

Practice Problems Plus

L2

1. Determine the mass of one mole of each of the following compounds:

CO_2 (44.0 g), SO_3 (80.1 g), Br_2 (159.8 g),
 H_2 (2.0 g), N_2 (28.0 g), NaOH (40.0 g),
 $\text{Al}_2(\text{SO}_4)_3$ (342.3 g), and $\text{Ba}(\text{NO}_3)_2$
 (261.3 g).

2. What is the mass, in grams, of 1.72 mol CaCl_2 ? (191 g)

Math

Handbook

For a math refresher and practice, direct students to significant figures, page R59.

Writing

Activity

Answers might include that in the mid 1800s, the concept of the mole was based on the element oxygen.

Interactive
Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 10.1.

with ChemASAP

SAMPLE PROBLEM 10.4

Finding the Molar Mass of a Compound

The decomposition of hydrogen peroxide (H_2O_2) provides sufficient energy to launch a rocket. What is the molar mass of hydrogen peroxide?

1 **Analyze** List the knowns and the unknown.

Knowns

- molecular formula = H_2O_2
- 1 molar mass H = 1 mol H = 1.0 g H
- 1 molar mass O = 1 mol O = 16.0 g O

Unknown

- molar mass = ? g

One mol of hydrogen peroxide has 2 mol of hydrogen atoms and 2 mol of oxygen atoms. Convert moles of atoms to grams by using conversion factors (g/mol) based on the molar mass of each element. The sum of the masses of the elements is the molar mass.

2 **Calculate** Solve for the unknown.

Convert moles of hydrogen and oxygen to grams of hydrogen and oxygen. Then add the results.

$$2 \text{ mol H} \times \frac{1.0 \text{ g H}}{1 \text{ mol H}} = 2.0 \text{ g H}$$

$$2 \text{ mol O} \times \frac{16.0 \text{ g O}}{1 \text{ mol O}} = 32.0 \text{ g O}$$

$$\text{molar mass of } \text{H}_2\text{O}_2 = 34.0 \text{ g}$$

3 **Evaluate** Does the result make sense?

The answer is the sum of two times the molar mass of hydrogen and oxygen. The answer is expressed to the tenth's place because the numbers being added are expressed to the tenth's place.

Practice Problems

7. Find the molar mass of PCl_3 . 8. What is the mass of 1.00 mol of sodium hydrogen carbonate?



Math

Handbook

For help with significant figures, go to page R59.

Interactive
Textbook

Problem-Solving 10.7
Solve Problem 7 with the help of an interactive guided tutorial.

with ChemASAP

10.1 Section Assessment

- Key Concept** What are three ways to measure the amount of something?
- Key Concept** Describe the relationship between Avogadro's number and one mole of any substance.
- Key Concept** How is the atomic mass of an element related to the molar mass of the element?
- Key Concept** How can you calculate the mass of a mole of a compound?
- How many moles is 1.50×10^{23} molecules NH_3 ?
- How many atoms are in 1.75 mol CHCl_3 ?
- What is the molar mass of CaSO_4 ?

296 Chapter 10

Writing

Activity

Report Research the history of Avogadro's number. What elements other than carbon have been used to define a mole? Write a report that summarizes your findings.

Interactive
Textbook

Assessment 10.1 Test yourself on the concepts in Section 10.1.

with ChemASAP

Section 10.1 Assessment

- by count, by mass, and by volume
- Add together the masses, expressed in grams, of each element in one mole of the compound.
- 2.49×10^{-1} mol NH_3
- 5.27×10^{24} atoms
- 136.2 g/mol
- One mole of any substance contains Avogadro's number (6.02×10^{23}) of representative particles.
- The molar mass of an element is its atomic mass expressed in grams.