SECTION 5.2

Mass and the Mole

Key Term

molar mass

In the previous section, you learned that working with moles is more convenient than working with individual particles. But is it convenient to measure substances in moles when doing an experiment? To do this, you would have to count all the particles each time you wanted to perform a reaction. That would be inconvenient because there is no device for counting particles.

How do chemists measure the quantities of substances they need when performing a chemical reaction? Scientists have developed sophisticated instruments, such as the one shown in **Figure 5.7**, to measure the relative masses of compounds accurately. They also have devised a way to determine the mass of a given number of particles, instead of counting individual particles.

Figure 5.7 This elaborate device is called a mass spectrometer. It is used to make precise mass measurements and to determine molecular structure.

Molar Mass: The Mass of One Mole

Recall that one atom of carbon-12 has a mass of exactly 12 u, and one mole (6.02×10^{23} atoms) of carbon-12 has a mass of exactly 12 g. Also recall that the atomic mass unit is defined using the carbon-12 isotope and that the atomic masses of all the other elements are defined using carbon-12 as the standard. These relationships are important, because it means that one mole of any element has a mass that is numerically equal to the element's atomic mass expressed in grams. For example, an atom of iron has an atomic mass of 55.85 u, and one mole of iron atoms has a mass of 55.85 g. Additional examples are shown in **Table 5.2**.

The relationship between mass and moles gives chemists a practical way to count atoms—by measuring their mass on a balance. Because of these relationships, you can use the periodic table to find the mass of one mole of any element.

Table 5.2 Average Atomic Mass and Mass of One Mole of Atoms of Four Elements

Element	Average Atomic Mass (u)	Mass of One Mole of Atoms (g)
boron	10.81	10.81
potassium	39.10	39.10
bromine	79.90	79.90
gold	196.97	196.97

Molar Mass: The Mass of One Mole

The term for the mass of one mole of a substance is **molar mass**. The symbol for molar mass is ***M***, and the unit is g/mol. The mass of one mole of atoms of any element in the periodic table is called its *atomic molar mass*. The units for this mass are g/mol. Similarly, you would call the mass of one mole of molecules of a substance its *molecular molar mass* and the mass of one mole of formula units of a substance its *formula unit molar mass*. The unit for all of these terms is g/mol.

molar mass the mass of one mole of a substance; the symbol for molar mass is *M*, and the unit is g/mol

Learning Check

8. Why is it not convenient to measure substances in moles?
9. What is the difference between atomic molar mass and molar mass?
10. What is the relationship between the atomic mass of an element in atomic mass units and the atomic molar mass of the same element in grams?
11. What is the mass of 6.02×10^{23} copper atoms?
12. In what other way can the mass of 6.02×10^{23} atoms be described? What is the unit for this value?
13. Why is the molar mass of most elements—for example, gold as shown in **Table 5.2**—not a whole number?

Linking Moles and Mass: The Molar Mass of a Compound

You have already seen that the value of the atomic mass of an element in the periodic table is the same as the value of its molar mass in grams. How do you find the molar mass of a compound?

To find the molar mass of a compound, such as water, you find the molar mass of each element in the periodic table, multiply by the number of atoms of each element, and add the values.

$$\begin{aligned} M_{H_2O} &= 2M_H + 1M_O \\ &= 2(1.01\text{ g/mol}) + 1(16.00\text{ g/mol}) \\ &= 18.02\text{ g/mol} \end{aligned}$$

Therefore, the molar mass of water is 18.02 g/mol.

The following Sample Problem shows how to determine the molar mass of a more complex compound. Study this problem, and then try the Practice Problems.

Sample Problem

Determining the Molar Mass of a Compound

Problem

What is the molar mass of aluminum sulfate, $Al_2(SO_4)_3(s)$?

What Is Required?

You need to find the mass of one mole of aluminum sulfate.

What Is Given?

You know the chemical formula: $Al_2(SO_4)_3(s)$

Plan Your Strategy	Act on Your Strategy
Use the periodic table to find the atomic molar mass of each element in aluminum sulfate. Multiply the atomic molar masses by the number of atoms of the element in the compound.	$2M_{Al} = 2(26.98\text{ g/mol}) = 53.96\text{ g/mol}$ $3M_S = 3(32.07\text{ g/mol}) = 96.21\text{ g/mol}$ $12M_O = 12(16.00\text{ g/mol}) = 192.00\text{ g/mol}$
Add the molar masses of the atoms of each element to get the molar mass of the compound.	$M_{Al_2(SO_4)_3} = 53.96\text{ g/mol} + 96.21\text{ g/mol} + 192.00\text{ g/mol}$ $= 342.2\text{ g/mol}$ The molar mass of aluminum sulfate is 342.2 g/mol.

Check Your Solution

Use rounded values for the atomic molar masses to get an estimate of the answer.

$(2 \times 27) + (3 \times 32) + (12 \times 16) = 342$ This estimate is close to the answer, 342.2 g/mol.

Practice Problems

31. State the molar mass of each element.
 a. sodium **c.** xenon
 b. tungsten **d.** nickel

32. Calculate the molar mass of phosphorus, $P_4(s)$.

33. Determine the molar mass of calcium phosphate, $Ca_3(PO_4)_2(s)$.

34. Calculate the molar mass of lead(II) nitrate, $Pb(NO_3)_2(s)$.

35. Determine the molar mass of the iron(III) thiocyanate ion, $FeSCN^{2+}(aq)$.

36. Calculate the molar mass of sodium stearate, $NaC_{17}H_{35}COO(s)$.

37. Calculate the molar mass of barium hydroxide octahydrate, $Ba(OH)_2{\bullet}8H_2O(s)$. (**Hint:** The molar mass of a hydrate must include the water component.)

38. Determine the molar mass of tetraphosphorus decoxide, $P_4O_{10}(s)$.

39. Calculate the molar mass of iron(II) ammonium sulfate hexahydrate, $(NH_4)_2Fe(SO_4)_2{\bullet}6H_2O(s)$.

40. The formula for a compound that contains an unknown element, A, is A_2SO_4. If the molar mass of the compound is 361.89 g/mol, what is the atomic molar mass of A?

Relationships among Moles, Mass, and Particles

One mole of a substance contains 6.02×10^{23} particles (atoms, molecules, ions, or formula units). The molar mass (the mass of one mole of a substance), then, represents the mass of 6.02×10^{23} particles. This means that connections exist among the number of particles, the molar mass, and the mass of a substance. It also means that you can count particles using a balance (with the help of some calculations), as shown in **Figure 5.8**.

Figure 5.8 By using a balance and mathematics, you can convert between mass and number of particles.

Notice that the amount in moles of a substance plays a central role in the relationships shown in **Figure 5.9**. You will find that these amounts will also play a central role in many of the calculations you do in this course.

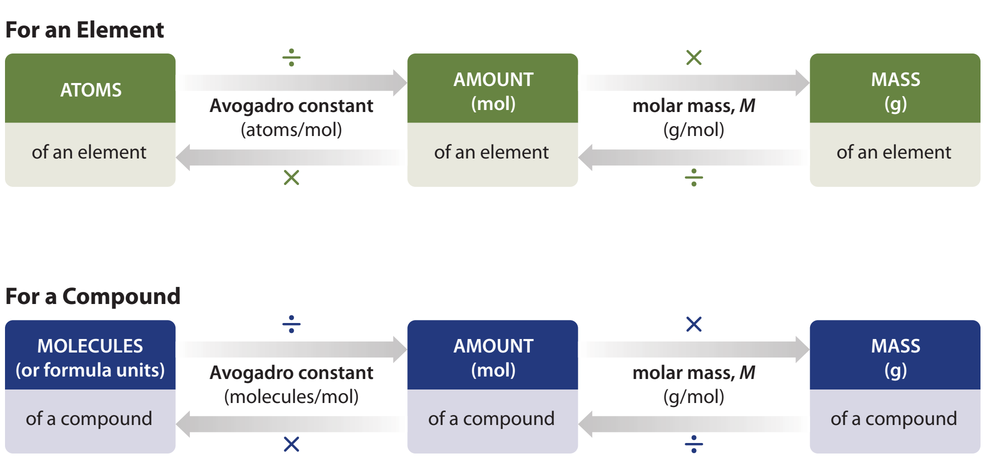

Figure 5.9 The Avogadro constant relates the number of particles of a substance to the amount in moles of the substance. Similarly, the molar mass relates the mass of a substance to the amount in moles.

Applying the Relationships among Moles, Mass, and Particles

Suppose that you have one mole of the element neon as shown in **Figure 5.10**. One mole of neon contains 6.02×10^{23} atoms and has a mass of 20.18 g. Its molar mass is therefore 20.18 g/mol. So, 6.02×10^{23} atoms of neon is 1 mol of neon or 20.18 g of neon.

The same holds true for compounds. Suppose that you have one mole of water. One mole of water contains 6.02×10^{23} molecules of water, and it has a mass of 18.02 g. Its molar mass is therefore 18.02 g/mol. So, 6.02×10^{23} molecules of water is 1 mol of water or 18.02 g of water. Could you use this relationship to calculate the amount in moles and the number of particles in 36.04 g of water?

Figure 5.10 One mole of the element neon is 20.18 g.

Determine *If this sign contains 10.0 g of neon, what amount in moles of neon is in the sign?*

Converting Amount in Moles to Mass

As mentioned earlier, if you wanted to perform a reaction, you would not count the particles required. This would not be practical. Instead, the relationships you have learned allow you to calculate the mass of each required reactant, using the amount required and the molar mass.

Suppose that you were asked to perform the following reaction:

$$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

You have been told to use 1.50 mol of zinc. How would you measure the zinc? The first step is to use molar mass to go from amount to mass using the equation below:

$$\text{mass} = \text{amount in moles} \times \text{molar mass}$$

The equation can also be written in symbols, as follows:

$$m = n \times M$$

This conversion is represented in **Figure 5.11**. Using the equation above, you would find the molar mass of zinc in the periodic table (65.41 g/mol) and then multiply it by the 1.50 mol of zinc required. You would get 98.12 g as your answer, which you could then measure on a balance.

$$\begin{aligned} m &= 1.50\ \cancel{\text{mol}} \times 65.41\ \frac{\text{g}}{\cancel{\text{mol}}} \\ &= 98.1\ \text{g} \end{aligned}$$

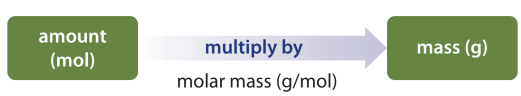

Figure 5.11 This graphic organizer shows how to convert from amount in moles to mass in grams.

The following Sample Problem and Practice Problems will help you practise converting amount to mass.

Sample Problem

Converting Amount to Mass

Problem

A chemist performs a reaction that produces 0.258 mol of silver chloride precipitate, $AgCl(s)$. What mass of precipitate is produced?

What Is Required?

You need to calculate the mass of silver chloride that is produced.

What Is Given?

You know the amount of silver chloride produced: 0.258 mol

You know the formula for silver chloride: $AgCl_2(s)$.

Plan Your Strategy	Act on Your Strategy
Use the periodic table to find the atomic molar masses of silver and chlorine. Multiply the atomic molar masses by the number of atoms of each element in the compound. Add the values calculated above to find the molar mass of the compound.	$1M_{Ag} = 1(107.87\ g/mol) = 107.87\ g/mole$ $2M_{Cl} = 2(35.45\ g/mol) = 70.90\ g/mole$ $M_{AgCl} = 1M_{Ag(s)} + 2M_{Cl(s)}$ $= 107.87\ g/mole + 70.90\ g/mole$ $= 178.77\ g/mole$ The molar mass of silver chloride is 178.77 g/mol.
Write the formula that relates mass to amount and molar mass. Substitute in the known values to calculate the mass.	$m = n \times M$ $= 0.258\ \cancel{mol} \times 178.77\ \frac{g}{\cancel{mol}}$ $= 46.1\ g$

Check Your Solution

0.258 mol is about $\frac{1}{4}$ of a mole, and 46 is about $\frac{1}{4}$ of 178, so the answer seems reasonable.

Practice Problems

41. Calculate the mass of 3.57 mol of vanadium.

42. Calculate the mass of 0.24 mol of carbon dioxide.

43. Calculate the mass of 1.28×10^{-3} mol of glucose, $C_6H_{12}O_6(s)$.

44. Calculate the mass of 0.0029 mol of magnesium bromide, $MgBr_2(s)$, in milligrams.

45. Name each compound, and then calculate its mass. Express this value in scientific notation.

a. 4.5×10^{-3} mol of $Co(NO_3)_2(s)$

b. 29.6 mol of $Pb(S_2O_3)_2(s)$

46. Determine the chemical formula for each compound, and then calculate its mass.

a. 4.9 mol of ammonium nitrate

b. 16.2 mol of iron(III) oxide

47. What is the mass of 1.6×10^{-3} mol of calcium chloride dihydrate, $CaCl_2{\cdot}2H_2O(s)$, in milligrams?

48. A litre of water contains 55.56 mol of water molecules. What is the mass of a litre of water, in kilograms?

49. For each group of three samples, determine the sample with the largest mass.

a. 2.34 mol of bromine, $Br_2(\ell)$; 9.80 mol of hydrogen sulfide, $H_2S(g)$; 0.568 mol of potassium permanganate, $KMnO_4(s)$

b. 13.7 mol of strontium iodate, $Sr(IO_3)_2(s)$; 15.9 mol of gold(III) chloride, $AuCl_3(s)$; 8.61 mol of bismuth silicate, $Bi_2(SiO_3)_3(s)$

50. Which has the smallest mass: 0.215 mol of potassium hydrogen sulfite, $KHSO_3(s)$; 1.62 mol of sodium hydrogen sulfite, $NaHSO_3(s)$; or 0.0182 mol of aluminum iodate, $Al(IO_3)_3(s)$?

Converting Mass to Amount in Moles

Often, the mass of a substance is known, but the amount in moles of the substance is not known. For example, sulfur dioxide, $SO_2(g)$, which is emitted in the exhaust gases from many power plants, is well known for its contribution to acid rain. As a result, many power plants, such as the one shown in **Figure 5.12**, remove the sulfur dioxide in their exhaust stacks using a reaction with substances such as calcium hydroxide, $Ca(OH)_2(s)$. By converting the mass of sulfur dioxide emitted to the amount emitted, technicians at the power plant can calculate and measure the amount of calcium hydroxide required to react with the sulfur dioxide.

Determining the amount of a substance from the mass of the substance involves rearranging the equation $m = n \times M$, as follows:

$$n = \frac{m}{M}$$

In other words,

$$\text{amount in moles} = \frac{\text{mass}}{\text{molar mass}}$$

Again, the molar mass of the substance is used as the conversion factor. This conversion is represented in **Figure 5.13**. A sample problem follows.

Figure 5.12 Power plants have developed the technology to "scrub" emissions, such as sulfur dioxide, out of the exhaust, using chemicals such as calcium hydroxide.

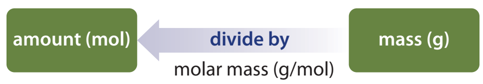

Figure 5.13 To convert from mass to amount, use the molar mass as a conversion factor.

Sample Problem

Converting Mass to Amount

Problem

What amount in moles is 15.3 g of sulfur dioxde, $SO_2(g)$, taken from a power plant exhaust stack?

What Is Required?

You need to convert 15.3 g of sulfur dioxide to the amount in moles.

What Is Given?

You know the mass of sulfur dioxide: 15.3 g

Plan Your Strategy	Act on Your Strategy
Use the periodic table to find the atomic molar masses of sulfur and oxygen. Multiply the atomic molar masses by the number of atoms of each element in the compound. Add these values to calculated the molar mass of the compound.	$M_{SO_2} = 1(M_S) + 2(M_O)$ $M_{SO_2} = 1(32.07\text{ g/mol}) + 2(16.00\text{ g/mol})$ $= 64.07\text{ g/mol}$ The molar mass of sulfur dioxide is 64.07 g/mol.
Divide the given mass by the molar mass to find the amount in moles.	$n = \frac{m}{M}$ $= \frac{15.3\cancel{g}}{64.07\ \cancel{g}/\text{mol}}$ $= 0.239\text{ mol}$ The amount of sulfur dioxide is 0.239 mol.

Check Your Solution

If you work backward, your answer in moles (0.239 mol) multiplied by the molar mass (64.07 g/mol) equals the mass given (15.3 g).

Practice Problems

51. Convert 29.5 g of ammonia to the amount in moles.

52. Determine the amount in moles of potassium thiocyanate, $KSCN(s)$, in 13.5 kg.

53. Determine the amount in moles of sodium dihydrogen phosphate, $NaH_2PO_4(s)$, in 105 mg.

54. Determine the amount in moles of xenon tetrafluoride, $XeF_4(s)$, in 22 mg.

55. Write the chemical formula for each compound, and then calculate the amount in moles in each sample.

- **a.** 3.7×10^{-3} g of silicon dioxide
- **b.** 25.38 g of titanium(IV) nitrate
- **c.** 19.2 mg of indium carbonate
- **d.** 78.1 kg of copper(II) sulfate pentahydrate

56. The characteristic odour of garlic comes from allyl sulfide, $(C_3H_5)_2S(\ell)$. Determine the amount in moles of allyl sulfide in 168 g.

57. Road salt, $CaCl_2(s)$, is often used on roads in the winter to prevent the build-up of ice. What amount in moles of calcium chloride is in a 20.0 kg bag of road salt?

58. Calculate the amount in moles of trinitrotoluene, $C_7H_5(NO_2)_3(s)$, an explosive, in 3.45×10^{-3} g.

59. Arrange the following substances in order from largest to smallest amount in moles:

- 865 mg of $Ni(NO_3)_2(s)$
- 9.82 g of $Al(OH)_3(s)$
- 10.4 g of $AgCl(s)$

60. Place the following substances in order from smallest to largest amount in moles, given 20.0 g of each:

- glucose, $C_6H_{12}O_6(s)$
- barium perchlorate, $Ba(ClO_4)_2(s)$
- tin(IV) oxide, $SnO_2(s)$

Conversions between Number of Particles and Mass

You have already learned how to convert number of particles to amount in moles, and amount in moles to number of particles. You have also converted between amount and mass. What about converting number of particles to mass, and vice versa? These conversions are shown in **Figure 5.14**.

Suppose that a chemist had a piece of copper wire with a mass of 2.34 g. How could the chemist calculate the number of copper atoms in the wire? Or suppose that you were given the challenge of calculating the mass of a sample of nitrogen gas which contained 5.34×10^{24} molecules of nitrogen. How would you figure out the steps in the calculation? Once again, the concept of the mole plays a central role in these types of calculations. Whether you are given the number of particles or the mass, your first step is to find the amount in moles of the substance.

Suggested Investigation

Inquiry Investigation 5-A, Exploring Conversions between Mass and Particles

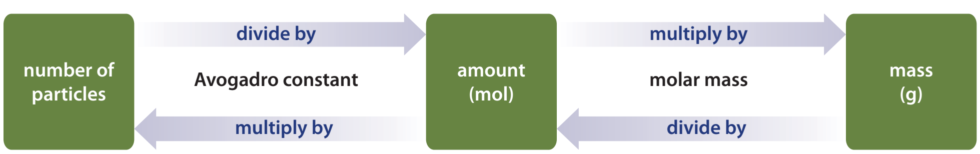

Figure 5.14 This graphic organizer shows how to convert among number of particles, amount in moles, and mass in grams.

Study the following Sample Problems to see examples of conversions between mass and number of particles. As the Alternative Solutions in these Sample Problems will show, you do not necessarily need to use mathematical formulas for the calculations if you are able to visualize the relationships.

Sample Problem

Converting Number of Particles to Mass

Problem

What is the mass of 4.72×10^{23} formula units of chromium(III) iodide, $CrI_3(s)$?

What Is Required?

You are asked to find the mass of chromium(III) iodide.

What Is Given?

You know the number of formula units of chromium(III) iodide: 4.72×10^{23}

You know the Avogadro constant: $N_A = 6.02 \times 10^{23}$

You know the conversion factors you will need to use: the Avogadro constant and the molar mass of chromium(III) iodide

Plan Your Strategy	Act on Your Strategy
Calculate the amount of chromium(III) iodide from the given number of formula units, using the Avogadro constant.	$n = \frac{N}{N_A}$ $= \frac{4.72 \times 10^{23} \cancel{\text{ formula units}}}{6.02 \times 10^{23} \cancel{\text{ formula units}}/\text{mol}}$ $= 0.784\ 053 \text{ mol}$
Calculate the mass from the amount in moles using the molar mass of chromium(III) iodide.	$m = n \times M$ $= 0.784\ 053 \cancel{\text{ mol}} \times 432.70 \frac{\text{g}}{\cancel{\text{mol}}}$ $= 339 \text{ g}$

Alternative Solution 1

Work with the units to set up the steps in your calculation. You are still finding the amount in moles first and then mass, but you are not using the mathematical formulas $n = \frac{N}{N_A}$ and $m = n \times M$.

Plan Your Strategy	Act on Your Strategy
Calculate the amount of chromium(III) iodide from the given number of formula units, using the Avogadro constant.	$n = 4.72 \times 10^{23} \cancel{\text{ formula units}} \times \frac{1 \text{ mol}}{6.02 \times 10^{23} \cancel{\text{ formula units}}}$ $= 0.784\ 053 \text{ mol}$
Calculate the mass from the amount in moles, using the molar mass of chromium(III) iodide.	$m = 0.784\ 053 \cancel{\text{ mol}} \times \frac{432.70 \text{ g}}{1 \cancel{\text{ mol}}}$ $= 339 \text{ g}$

Alternative Solution 2

The calculation can be arranged on one line, as follows:

$$m = 4.72 \times 10^{23} \cancel{\text{ formula units}} \times \frac{1 \cancel{\text{ mol}}}{6.02 \times 10^{23} \cancel{\text{ formula units}}} \times \frac{432.70 \text{ g}}{1 \cancel{\text{ mol}}}$$
$$= 339 \text{ g}$$

This arrangement can be used in most multi-step problems, if you are using the units to calculate the answer.

Check Your Solution

The number 4.72 is about $\frac{3}{4}$ of 6.02 (with the same power of 10), and 339 g is about $\frac{3}{4}$ of the numerical value of the molar mass 432.70 g/mol, so the answer is reasonable.

Sample Problem

Converting Mass to Number of Particles

Problem

Phosphoryl chloride, $POCl_3(\ell)$, is an important compound in the production of flame retardants. How many molecules of phosphoryl chloride are in a 25.2 g sample?

What Is Required?

You are asked to find the number of molecules of phosphoryl chloride.

What Is Given?

You are given the mass of a phosphoryl chloride sample: 25.2 g
You know the Avogadro constant: $N_A = 6.02 \times 10^{23}$

Plan Your Strategy	Act on Your Strategy
Calculate the amount of phosphoryl chloride from the given mass, using the molar mass.	$n = \frac{m}{M}$ $= \frac{25.2\ \cancel{g}}{153.32\ \cancel{g}/\text{mol}}$ $= 0.164\ 362\ \text{mol}$
Calculate the number of molecules of phosphoryl chloride from the amount in moles, using the Avogadro constant.	$N = n \times N_A$ $= 0.164\ 362\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}}$ $= 9.89 \times 10^{22}$ molecules

Alternative Solution

Work with the units to set up the steps in your calculation. You are still finding amount in moles first and then molecules, but you are not using the mathematical formulas $n = \frac{m}{M}$ and $N = n \times N_A$.

Plan Your Strategy	Act on Your Strategy
Calculate the amount of phosphoryl chloride from the given mass, using the molar mass.	$n = 25.2\ \cancel{g} \times \frac{1\ \text{mol}}{153.32\ \cancel{g}}$ $= 0.164\ 362\ \text{mol}$
Calculate the number of molecules of phosphoryl chloride from the amount, using the Avogadro constant.	$N = 0.164\ 362\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}}$ $= 9.89 \times 10^{22}$ molecules

Again, this calculation can be arranged on one line, as follows:

$$N = 25.2\ \cancel{g} \times \frac{1\ \cancel{\text{mol}}}{153.32\ \cancel{g}} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \cancel{\text{mol}}}$$
$$= 9.89 \times 10^{22}\ \text{molecules}$$

Check Your Solution

The number 25.2 g is about $\frac{1}{6}$ of the molar mass, so the number of molecules should be about $\frac{1}{6}$ of the Avogadro constant. Since 9.89×10^{22} is about $\frac{1}{6}$ of 6.02×10^{23}, the answer is reasonable.

Practice Problems

61. Calculate the mass of each sample.

a. 1.05×10^{26} atoms of neon, $Ne(g)$

b. 2.7×10^{24} molecules of phosphorus trichloride, $PCl_3(\ell)$

c. 8.72×10^{21} molecules of karakin, $C_{15}H_{21}N_3O_{15}(s)$

d. 6.7×10^{27} formula units of sodium thiosulfate, $Na_2S_2O_3(s)$

62. Determine the number of molecules or formula units in each sample.

a. 32.4 g of lead(II) phosphate, $Pb_3(PO_4)_2(s)$

b. 8.62×10^{-3} g of dinitrogen pentoxide, $N_2O_5(s)$

c. 48 kg of molybdenum(VI) oxide, $MoO_3(s)$

d. 567 g of tin(IV) fluoride, $SnF_4(s)$

63. Sodium hydrogen carbonate, $NaHCO_3(s)$, is the principal ingredient in many stomach-relief medicines.

a. A teaspoon of a particular brand of stomach-relief medicine contains 6.82×10^{22} formula units of sodium hydrogen carbonate. What mass of sodium hydrogen carbonate is in the teaspoon?

b. The bottle of this stomach-relief medicine contains 350 g of sodium hydrogen carbonate. How many formula units of sodium hydrogen carbonate are in the bottle?

64. Riboflavin, $C_{17}H_{20}N_4O_6(s)$, is an important vitamin in the metabolism of fats, carbohydrates, and proteins in your body.

a. The current recommended dietary allowance (RDA) of riboflavin for adult men is 1.3 mg/day. How many riboflavin molecules are in this RDA?

b. The RDA of riboflavin for adult women contains 1.8×10^{18} molecules of riboflavin. What is the RDA for adult women, in milligrams?

65. What is the mass, in grams, of a single atom of platinum?

66. Rubbing alcohol often contains propanol, $C_3H_7OH(\ell)$. Suppose that you have an 85.9 g sample of propanol.

a. How many carbon atoms are in the sample?

b. How many hydrogen atoms are in the sample?

c. How many oxygen atoms are in the sample?

67. a. How many formula units are in a 3.14 g sample of aluminum sulfide, $Al_2S_3(s)$?

b. How many ions (aluminum and sulfide), in total, are in this sample?

68. Which of the following two substances contains the greater mass?

- 6.91×10^{22} molecules of nitrogen dioxide, $NO_2(g)$
- 6.91×10^{22} formula units of gallium arsenide, $GaAs(s)$

69. Many common dry-chemical fire extinguishers contain ammonium phosphate, $(NH_4)_3PO_4(s)$, as their principal ingredient. If a sample of ammonium phosphate contains 4.5×10^{21} atoms of nitrogen, what is the mass of the sample?

70. Place the following three substances in order, from greatest to smallest number of hydrogen atoms:

- 268 mg of sucrose, $C_{12}H_{22}O_{11}(s)$
- 15.2 g of hydrogen cyanide, $HCN(\ell)$
- 0.0889 mol of acetic acid, $CH_3COOH(\ell)$

Suggested Investigation

Inquiry Investigation 5-B, Using the Mole for Measuring and Counting Particles

Using the Mole

In this chapter, you learned about an important concept in chemistry: the mole. You also learned about the relationships among the number of particles in a substance, the amount of a substance, and the mass of a substance. Knowing these important relationships will help you explore the mole concept and its uses. In the next chapter, you will learn how the mass proportions of the elements in a compound relate to the formula for the compound and how chemists use their understanding of molar mass to find out important information about chemical compounds.

Section 5.2 REVIEW

Section Summary

- The mass of one atom of an element in atomic mass units has the same numerical value as the mass of one mole of atoms of the same element in grams.
- Molar mass is an important tool for converting back and forth between the mass and amount of an element or a compound.
- Conversions can be made between the number of individual particles of a substance and the mass of the substance, using both the Avogadro constant and the molar mass.
- All of these conversions are important when calculating and measuring the amounts of substances in a chemical reaction.

Review Questions

1. K/U Compare and constrast the following pairs of terms. Give examples of each.
   a. atomic molar mass, molar mass
   b. molecular molar mass, formula unit molar mass
   c. formula unit molar mass, atomic molar mass
   d. molar mass, molecular molar mass
2. C Use a flowchart to show the relationships among number of particles, amount in moles, and mass in grams.
3. C Use a flowchart to show how the atomic mass and atomic molar mass of an element are related.
4. T/I Determine the amount in moles of gallium oxide, $Ga_2O_3(s)$, in a 45.2 g sample.
5. T/I What is the mass of 3.2×10^2 mol of cerium nitrate, $Ce(NO_3)_3(s)$?
6. T/I Calculate the amount in moles of strontium chloride, $SrCl_2(s)$, in a 28.6 kg sample.
7. T/I What is the mass of 0.68 mol of iron(III) sulfate, $Fe_2(SO_4)_3(s)$?
8. T/I What is the mass of 2.9×10^{26} molecules of dinitrogen pentoxide, $N_2O_5(g)$?
9. T/I Calculate the number of oxygen atoms in 15.2 g of trinitrotoluene, $C_7H_5(NO_2)_3(s)$.
10. T/I Which has more sulfur atoms: 13.4 g of potassium thiocyanate, KSCN(s), or 0.067 mol of aluminum sulfate, $Al_2(SO_4)_3$?
11. T/I Which has a greater amount in moles: a sample of sulfur trioxide containing 4.9×10^{22} atoms of oxygen or a 4.9 g sample of carbon dioxide?
12. A Imagine that you are an environmental chemist who is testing drinking water for water hardness. A sample of water you test has 3.5×10^{-2} mg of dissolved calcium carbonate, $CaCO_3(aq)$.
    a. How many formula units of calcium carbonate are in the sample?
    b. How many oxygen atoms are in the calcium carbonate in the sample?
13. A A chemist is testing for lead content in water samples taken downstream from a battery manufacturing plant. Health Canada suggests that drinking water should have a maximum lead content of 0.010 mg/L of water. If a test reveals that a 1 L water sample contains 3.1×10^{17} atoms of lead, is the water safe to drink? Explain.
14. T/I Copy and complete the following table.

Number of Particles, Amount, and Mass of Selected Elements and Compounds

Substance	Number of Particles	Amount (mol)	Mass (g)
$P_4(s)$		13.2	
$Ba(MnO_4)_2(s)$	6.7×10^{20}		
$C_5H_9NO_4(s)$			19.62

15. A Methyl salicylate, $C_6H_4(OH)COOCH_3(s)$, is used in many consumer products, such as mouthwash, as a flavouring. A mouthwash sample contains 1.38×10^{18} molecules of methyl salicylate. What is the mass of the methyl salicylate in the sample?

16. T/I Determine the order of the following three substances, from smallest to greatest number of carbon atoms: 5.6×10^{23} molecules of benzoic acid, $C_6H_5COOH(s)$; 1.3 mol of acetic acid, $CH_3COOH(\ell)$; 0.17 kg of oxalic acid, HOOCCOOH(s).