10.1

The Mole: A Measurement of Matter

Connecting to Your World

You could measure the amount of sand in a sand sculpture by counting each grain of sand, but it would be much easier to weigh the sand. You'll discover how chemists measure the amount of a substance using a unit called a mole, which relates the number of particles to the mass.

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Measuring Matter

What are three methods for measuring the amount of something?

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10.1 The Mole: A Measurement of Matter > Measuring Matter

You often measure the amount of something by one of three different methods—by count, by mass, and by volume.

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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?

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SAMPLE PROBLEM 10.1

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 ⟶ dozens of apples ⟶ mass of apples.

SAMPLE PROBLEM 10.1

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.

$$\text{mass of apples} = 90 \cancel{\text{ apples}} \times \frac{1 \cancel{\text{ dozen apples}}}{12 \cancel{\text{ apples}}} \times \frac{2.0 \text{ kg apples}}{1 \cancel{\text{ dozen apples}}}$$

$$= 15 \text{ kg apples}$$

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

SAMPLE PROBLEM 10.1

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 × 2.0 kg/dozen).

What Is a Mole?

How is Avogadro's number related to a mole of any substance?

A mole of any substance contains Avogadro's number of representative particles, or 6.02×10^{23} representative particles.

The term **representative particle** refers to the species present in a substance: usually atoms, molecules, or formula units.

Converting Number of Particles to Moles

One **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.**

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

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}

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?

SAMPLE PROBLEM 10.2

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

Knowns

- number of atoms = 1.25×10^{23} atoms Mg
- 1 mol Mg = 6.02×10^{23} atoms Mg
- The desired conversion is: atoms ⟶ moles

Unknown

- moles = ? mol Mg

SAMPLE PROBLEM 10.2

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.

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

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

SAMPLE PROBLEM 10.2

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.

Converting Moles to Number of Particles

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

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)?

SAMPLE PROBLEM 10.3

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

Knowns

- number of moles = 2.12 mol C_3H_8
- 1 mol C_3H_8 = 6.02×10^{23} molecules C_3H_8
- 1 molecule C_3H_8 = 11 atoms
  (3 carbon atoms and 8 hydrogen atoms)
- The desired conversion is: moles ⟶ molecules ⟶ atoms.

Unknown

- number of atoms = ? atoms

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

SAMPLE PROBLEM 10.3

Calculate ***Solve for the unknown.***

The first conversion factor is $\frac{6.02 \times 10^{23}\ \text{molecules } C_3H_8}{1\ \text{mol } C_3H_8}$.

The second conversion factor is $\frac{11\ \text{atoms}}{1\ \text{molecule } C_3H_8}$.

Multiply the moles of C_3H_8 by the proper conversion factors:

$$2.12\ \cancel{\text{mol } C_3H_8} \times \frac{6.02 \times 10^{23}\ \cancel{\text{molecules } C_3H_8}}{1\ \cancel{\text{mol } C_3H_8}} \times \frac{11\ \text{atoms}}{1\ \cancel{\text{molecule } C_3H_8}}$$

$$= 1.4039 \times 10^{25}\ \text{atoms} = 1.40 \times 10^{25}\ \text{atoms}$$

SAMPLE PROBLEM 10.3

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.

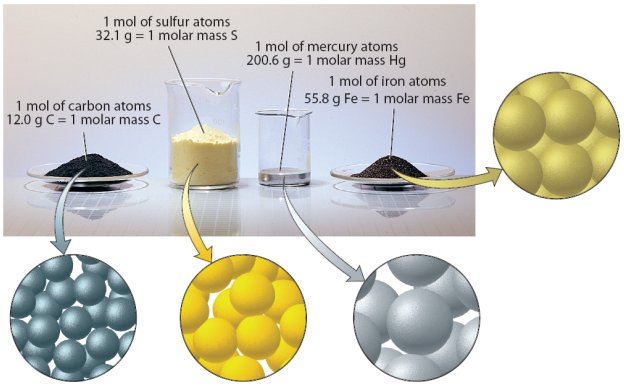
The Mass of a Mole of an Element

How is the atomic mass of an element related to the molar mass of an element?

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.**

One molar mass of carbon, sulfur, mercury, and iron are shown.

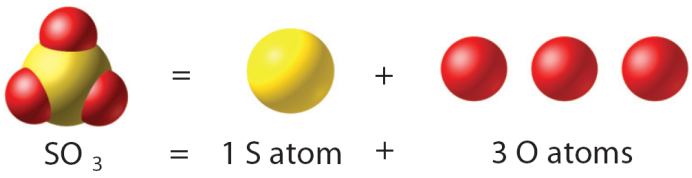


The Mass of a Mole of a Compound

How is the mass of a mole of a compound calculated?

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.

Substitute the unit grams for atomic mass units. Thus 1 mol of SO_3 has a mass of 80.1 g.



SO_3 = 1 S atom + 3 O atoms

1 S atom + 3 O atoms

32.1 amu + 16.0 amu + 16.0 amu + 16.0 amu = 80.1 amu

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?

SAMPLE PROBLEM 10.4

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.

SAMPLE PROBLEM 10.4

Calculate ***Solve for the unknown.***

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

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

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

$$\text{molar mass of } H_2O_2 = 34.0\ \text{g}$$

SAMPLE PROBLEM 10.4

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.