Chapter 7 Chemical Quantities

The Mole

Collections of items include dozen, gross, and mole.

24 Cans
144 Pencils
500 Sheets
12 Eggs
Collection Terms

A collection term states a specific number of items.

- 1 dozen donuts = 12 donuts
- 1 ream of paper = 500 sheets
- 1 case = 24 cans
A Mole of Atoms

A **mole (mol)** is a collection that contains

- the same number of particles as there are carbon atoms in 12.01 g of carbon.
- \(6.022 \times 10^{23}\) atoms of an element (**Avogadro’s number**).

<table>
<thead>
<tr>
<th>1 mol of Element</th>
<th>Number of Atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mol C</td>
<td>(6.022 \times 10^{23}) C atoms</td>
</tr>
<tr>
<td>1 mol Na</td>
<td>(6.022 \times 10^{23}) Na atoms</td>
</tr>
<tr>
<td>1 mol Au</td>
<td>(6.022 \times 10^{23}) Au atoms</td>
</tr>
</tbody>
</table>
A Mole of A Compound

A mole

- of a *covalent compound* has Avogadro’s number of molecules
  
  \[ 1 \text{ mol CO}_2 = 6.022 \times 10^{23} \text{ CO}_2 \text{ molecules} \]
  
  \[ 1 \text{ mol H}_2\text{O} = 6.022 \times 10^{23} \text{ H}_2\text{O} \text{ molecules} \]

- of an *ionic compound* contains Avogadro’s number of formula units
  
  \[ 1 \text{ mol NaCl} = 6.022 \times 10^{23} \text{ NaCl formula units} \]
  
  \[ 1 \text{ mol K}_2\text{SO}_4 = 6.022 \times 10^{23} \text{ K}_2\text{SO}_4 \text{ formula units} \]
TABLE 7.1 Number of Particles in 1-Mol Samples

<table>
<thead>
<tr>
<th>Substance</th>
<th>Number and Type of Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mol of Al</td>
<td>$6.022 \times 10^{23}$ atoms of Al</td>
</tr>
<tr>
<td>1 mol of Fe</td>
<td>$6.022 \times 10^{23}$ atoms of Fe</td>
</tr>
<tr>
<td>1 mol of H$_2$O</td>
<td>$6.022 \times 10^{23}$ molecules of H$_2$O</td>
</tr>
<tr>
<td>1 mol of vitamin C (C$_6$H$_8$O$_6$)</td>
<td>$6.022 \times 10^{23}$ molecules of vitamin C</td>
</tr>
<tr>
<td>1 mol of NaCl</td>
<td>$6.022 \times 10^{23}$ formula units of NaCl</td>
</tr>
</tbody>
</table>
Avogadro’s Number

Avogadro’s number \( (6.022 \times 10^{23}) \) can be written as an equality and two conversion factors.

Equality:

\[
1 \text{ mol} = 6.022 \times 10^{23} \text{ particles}
\]

Conversion Factors:

\[
\frac{6.022 \times 10^{23} \text{ particles}}{1 \text{ mol}} \quad \text{and} \quad \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ particles}}
\]
Using Avogadro’s Number

Avogadro’s number converts *moles* of a substance to the number of *particles*.

How many Cu atoms are in 0.50 mol of Cu?

\[
0.50 \text{ mol Cu} \times \frac{6.022 \times 10^{23} \text{ Cu atoms}}{1 \text{ mol Cu}} = 3.0 \times 10^{23} \text{ Cu atoms}
\]
Using Avogadro’s Number

Avogadro’s number is used to convert the number of particles of a substance to moles.

How many moles of CO$_2$ are in 2.50 x 10$^{24}$ molecules of CO$_2$?

\[
\begin{align*}
2.50 \times 10^{24} \text{ molecules CO}_2 & \times \frac{1 \text{ mol CO}_2}{6.022 \times 10^{23} \text{ molecules CO}_2} \\
& = 4.15 \text{ mol of CO}_2
\end{align*}
\]
1. The number of atoms in 2.0 mol of Al is
   A. 2.0 Al atoms
   B. 3.0 x 10^{23} Al atoms
   C. 1.2 x 10^{24} Al atoms

2. The number of moles of S in 1.8 x 10^{24} atoms of S is
   A. 1.0 mol of S atoms
   B. 3.0 mol of S atoms
   C. 1.1 x 10^{48} mol of S atoms
Solution

1. \( \text{2.0 mol Al} \times \frac{6.022 \times 10^{23} \text{ Al atoms}}{1 \text{ mol Al}} = 1.2 \times 10^{24} \text{ Al atoms (C)} \)

2. \( \text{1.8} \times 10^{24} \text{ S atoms} \times \frac{1 \text{ mol S}}{6.022 \times 10^{23} \text{ S atoms}} = 3.0 \text{ mol of S atoms (B)} \)
Subscripts and Moles

The **subscripts in a formula** state
- the relationship of atoms in the formula
- the moles of each element in 1 mol of compound

**Glucose**

\[ \text{C}_6\text{H}_{12}\text{O}_6 \]

1 molecule: 6 atoms of C      12 atoms of H     6 atoms of O
1 mol:       6 mol of C      12 mol of H     6 mol of O
Subscripts State Atoms and Moles

Aspirin  $\text{C}_9\text{H}_8\text{O}_4$

Number of atoms in 1 molecule

- Carbon (C)
- Hydrogen (H)
- Oxygen (O)
Factors from Subscripts

**Subscripts** used for conversion factors

- relate moles of each element in 1 mol of compound
- for aspirin $C_9H_8O_4$ can be written as

\[
\frac{9 \text{ mol C}}{1 \text{ mol } C_9H_8O_4} \quad \frac{8 \text{ mol H}}{1 \text{ mol } C_9H_8O_4} \quad \frac{4 \text{ mol O}}{1 \text{ mol } C_9H_8O_4}
\]

and

\[
\frac{1 \text{ mol } C_9H_8O_4}{9 \text{ mol C}} \quad \frac{1 \text{ mol } C_9H_8O_4}{8 \text{ mol H}} \quad \frac{1 \text{ mol } C_9H_8O_4}{4 \text{ mol O}}
\]
Calculating Atoms or Molecules

Guide to Calculating the Atoms or Molecules of a Substance

STEP 1
Determine the given number of moles.

STEP 2
Write a plan to convert moles to atoms or molecules.

STEP 3
Use Avogadro’s number to write conversion factors.

STEP 4
Set up problem to convert given moles to atoms or molecules.
Learning Check

How many O atoms are in 0.150 mol of aspirin, C$_9$H$_8$O$_4$?
Solution

How many O atoms are in 0.150 mol of aspirin, C$_9$H$_8$O$_4$?

**STEP 1**  Given  0.150 mol of C$_9$H$_8$O$_4$

Need  molecules of C$_9$H$_8$O$_4$

**STEP 2**  Plan

moles of aspirin $\rightarrow$ moles of O $\rightarrow$ atoms of O
Solution (continued)

**STEP 3  Equalities/Conversion Factors**

\[
1 \text{ mol of } C_9H_8O_4 = 4 \text{ mol of } O
\]

\[
\frac{1 \text{ mol } C_9H_8O_4}{4 \text{ mol } O}\ \text{ and } \frac{4 \text{ mol } O}{1 \text{ mol } C_9H_8O_4}
\]

\[
1 \text{ mol of } O = 6.022 \times 10^{23} \text{ atoms of } O
\]

\[
\frac{1 \text{ mole } O}{6.022 \times 10^{23} \text{ atoms } O}\ \text{ and } \frac{6.022 \times 10^{23} \text{ atoms } O}{1 \text{ mol } O}
\]

**STEP 4  Set Up Problem**

\[
0.150 \text{ mol } C_9H_8O_4 \times \frac{4 \text{ mol } O}{1 \text{ mol } C_9H_8O_4} \times \frac{6.022 \times 10^{23} \text{ O atoms}}{1 \text{ mol } O}
\]

\[
= 3.61 \times 10^{23} \text{ O atoms}
\]
Lithium carbonate produces a red color in fireworks.
Molar Mass

The **molar mass**

- is the mass of one mol of an element or compound
- is the atomic mass expressed in grams
Molar Mass from the Periodic Table

6.022 \times 10^{23} \text{ atoms of C} = 1 \text{ mol of C atoms} = 12.01 \text{ g of C atoms}

1 \text{ mol of silver has a mass of 107.9 g}

1 \text{ mol of carbon has a mass of 12.01 g}

1 \text{ mol of sulfur has a mass of 32.07 g}
Learning Check

Give the molar mass for

A. 1 mol of K atoms  =  __________

B. 1 mol of Sn atoms  =  __________
Solution

Give the molar mass for

A. 1 mol of K atoms  =  39.10 g

B. 1 mol of Sn atoms  =  118.7 g
Guide to Calculating Molar Mass

STEP 1
Obtain the molar mass of each element.

STEP 2
Multiply each molar mass by the number of moles (subscript) in the formula.

STEP 3
Calculate the molar mass by adding the masses of the elements.
Molar Mass of a Compound

For a compound, the molar mass is the sum of the molar masses of the elements in the formula.

Example: Calculate the molar mass of CaCl$_2$.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of Moles</th>
<th>Atomic Mass</th>
<th>Total Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>1</td>
<td>40.08 g/mol</td>
<td>40.08 g</td>
</tr>
<tr>
<td>Cl</td>
<td>2</td>
<td>35.45 g/mol</td>
<td>70.90 g</td>
</tr>
<tr>
<td>CaCl$_2$</td>
<td></td>
<td></td>
<td>110.98 g</td>
</tr>
</tbody>
</table>
Molar Mass of $\text{K}_3\text{PO}_4$

Determine the molar mass of $\text{K}_3\text{PO}_4$.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of Moles</th>
<th>Atomic Mass</th>
<th>Total Mass in $\text{K}_3\text{PO}_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>3</td>
<td>39.10 g/mol</td>
<td>117.3 g</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>30.97 g/mol</td>
<td>30.97 g</td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>16.00 g/mol</td>
<td>64.00 g</td>
</tr>
<tr>
<td>$\text{K}_3\text{PO}_4$</td>
<td></td>
<td></td>
<td>212.3 g</td>
</tr>
</tbody>
</table>
Some One-Mol Quantities

1-Mol Quantities

S  Fe  NaCl  K₂Cr₂O₇  C₁₂H₂₂O₁₁
Learning Check

Calculate the molar mass for $\text{Al(OH)}_3$ with four significant figures.

1) 44.00 g/mol
2) 75.00 g/mol
3) 78.00 g/mol
STEP 1 Obtain the molar mass of each element.
   Al  26.98 g/mol   O  16.00 g/mol   H  1.008 g/mol

STEP 2 Multiply each by the subscript.
   \[
   \begin{align*}
   1 \text{ mol Al} & \times \frac{26.98 \text{ g Al}}{1 \text{ mol Al}} = 26.98 \text{ g} \\
   3 \text{ mol O} & \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 48.00 \text{ g} \\
   3 \text{ mol H} & \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 3.024 \text{ g}
   \end{align*}
   \]

STEP 3 Calculate the molar mass by adding the masses of the elements.
   \[
   1 \text{ mol of Al(OH)}_3 = 78.00 \text{ g} \quad (3)
   \]
Learning Check

Prozac, C_{17}H_{18}F_{3}NO, is an antidepressant that inhibits the uptake of serotonin by the brain. What is the molar mass of Prozac?

1) 40.06 g/mol
2) 262.0 g/mol
3) 309.4 g/mol
Prozac, C\textsubscript{17}H\textsubscript{18}F\textsubscript{3}NO, is an antidepressant that inhibits the uptake of serotonin by the brain. What is the molar mass of Prozac?

**STEP 1  Obtain the molar mass of each element.**

- C 12.01 g/mol
- H 1.008 g/mol
- F 19.00 g/mol
- N 14.01 g/mol
- O 16.00 g/mol

**STEP 2  Multiply each by the subscript in the formula.**

\[
\begin{align*}
17 \text{ mol C} & \times \frac{12.01 \text{ g C}}{1 \text{ mol C}} = 204.2 \text{ g} \\
18 \text{ mol H} & \times \frac{1.008 \text{ g H}}{1 \text{ mol H}} = 18.14 \text{ g}
\end{align*}
\]
Solution (continued)

**STEP 2**

\[
\begin{align*}
3 \text{ mol F} & \times \frac{19.00 \text{ g F}}{1 \text{ mol F}} = 57.00 \text{ g} \\
1 \text{ mol N} & \times \frac{14.01 \text{ g N}}{1 \text{ mol N}} = 14.01 \text{ g} \\
1 \text{ mol O} & \times \frac{16.00 \text{ g O}}{1 \text{ mol O}} = 16.00 \text{ g}
\end{align*}
\]

**STEP 3**

1 mol of \( \text{C}_{17}\text{H}_{18}\text{F}_{3}\text{NO} \) = 309.4 g
Table salt is NaCl.
Molar Mass Factors

Molar mass conversion factors

- are written from molar mass
- relate grams and moles of an element or compound

Example: Write molar mass factors for methane CH₄ used in gas cook tops and gas heaters.

Molar mass:

\[ 1 \text{ mol CH}_4 = 16.04 \text{ g} \]

Conversion factors:

\[ \frac{16.04 \text{ g CH}_4}{1 \text{ mol CH}_4} \] and \[ \frac{1 \text{ mol CH}_4}{16.04 \text{ g CH}_4} \]
Acetic acid $\text{HC}_2\text{H}_3\text{O}_2$ gives the sour taste to vinegar. Write an equality and two molar mass conversion factors for acetic acid.
Solution

Acetic acid $\text{HC}_2\text{H}_3\text{O}_2$ gives the sour taste to vinegar. Write an equality and two molar mass conversion factors for acetic acid.

**Equality:**

1 mol of acetic acid $= 60.05 \text{ g of acetic acid}$

**Molar mass conversion factors:**

$\frac{1 \text{ mol acetic acid}}{60.05 \text{ g acetic acid}}$ and $\frac{60.05 \text{ g acetic acid}}{1 \text{ mol acetic acid}}$
Guide to Calculation Using Molar Mass

Guide to Calculating the Moles (or Grams) of a Substance from Grams (or Moles)

STEP 1
Determine the given number of moles (or grams).

STEP 2
Write a plan to convert moles to grams (or grams to moles).

STEP 3
Determine the molar mass and write conversion factors.

STEP 4
Set up problem to convert given moles to grams (or grams to moles).
Aluminum is used to build lightweight bicycle frames. How many grams of Al are in 3.00 mol of Al?
Solution

STEP 1  Given  3.00 mol of Al  Need  grams of Al

STEP 2  Plan  moles of Al  →  grams of Al

STEP 3  Equalities/Conversion Factors

\[
\text{1 mol of Al} = 26.98 \text{ g of Al} \\
\frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \quad \text{and} \quad \frac{26.98 \text{ g Al}}{1 \text{ mol Al}}
\]
Solution (continued)

**STEP 4  Set Up Problem**
Set up with molar mass as a factor:

\[
3.00 \text{ mol Al} \times \frac{26.98 \text{ g Al}}{1 \text{ mol Al}} = 80.9 \text{ g of Al}
\]

*molar mass factor for Al*
Learning Check

The artificial sweetener aspartame (NutraSweet), $\text{C}_{14}\text{H}_{18}\text{N}_2\text{O}_5$, is used to sweeten diet foods, coffee, and soft drinks. How many moles of aspartame are present in 225 g of aspartame?
Solution

STEP 1  Given  225 g of C_{14}H_{18}N_{2}O_{5}  Need  moles

STEP 2  Plan  g of aspartame  moles of aspartame

STEP 3  Equalities/Conversion Factors

\[
1 \text{ mol aspartame} = 294.3 \text{ g}
\]
\[
\frac{1 \text{ mol aspartame}}{294.3 \text{ g aspartame}} \quad \text{and} \quad \frac{294.3 \text{ g aspartame}}{1 \text{ mol aspartame}}
\]

STEP 4  Set Up Problem

\[
225 \text{ g aspartame} \times \frac{1 \text{ mol aspartame}}{294.3 \text{ g aspartame}} = 0.765 \text{ mol of aspartame}
\]

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Learning Check

Allyl sulfide, $\text{C}_6\text{H}_{10}\text{S}$, is a compound that has the odor of garlic. How many moles of $\text{C}_6\text{H}_{10}\text{S}$ are in 225 g of $\text{C}_6\text{H}_{10}\text{S}$?
**Solution**

**STEP 1** Given 225 g of C$_6$H$_{10}$S  **Need** moles of C$_6$H$_{10}$S

**STEP 2** Plan  g of C$_6$H$_{10}$S $\rightarrow$ moles of C$_6$H$_{10}$S

**STEP 3** Equalities/Conversion Factors

\[
1 \text{ mol of C}_6\text{H}_{10}\text{S} = 114.21 \text{ g of C}_6\text{H}_{10}\text{S}
\]
\[
\frac{1 \text{ mol C}_6\text{H}_{10}\text{S}}{114.21 \text{ g C}_6\text{H}_{10}\text{S}} \text{ and } \frac{114.21 \text{ g C}_6\text{H}_{10}\text{S}}{1 \text{ mol C}_6\text{H}_{10}\text{S}}
\]

**STEP 3** Set Up Problem

\[
225 \text{ g C}_6\text{H}_{10}\text{S} \times \frac{1 \text{ mol C}_6\text{H}_{10}\text{S}}{114.21 \text{ g C}_6\text{H}_{10}\text{S}} = 1.97 \text{ mol C}_6\text{H}_{10}\text{S}
\]
Guide to Converting Grams to Particles

<table>
<thead>
<tr>
<th>Mass</th>
<th>Moles</th>
<th>Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grams of element (g/mol)</td>
<td>Moles of element</td>
<td>Atoms (or ions)</td>
</tr>
<tr>
<td></td>
<td>Avogadro’s Number</td>
<td>Formula Subscripts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grams of compound (g/mol)</td>
<td>Moles of compound</td>
<td>Molecules (or formula units)</td>
</tr>
<tr>
<td></td>
<td>Avogadro’s Number</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Learning Check

How many molecules of H₂O are in 24.0 g of H₂O?

1) $4.52 \times 10^{23}$

2) $1.44 \times 10^{25}$

3) $8.02 \times 10^{23}$
Solution

**STEP 1** Given 24.0 g of H\(_2\)O
Need molecules of H\(_2\)O

**STEP 2** Plan

\[
g \text{ of } H_2O \rightarrow \text{ moles of } H_2O \rightarrow \text{ molecules of } H_2O
\]

**STEP 3** Equalities/Conversion Factors

\[
1 \text{ mol of } H_2O = 18.02 \text{ g of } H_2O
\]

\[
\frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \text{ and } \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O}
\]
Solution (continued)

STEP 3 Equalities/Conversion Factors (continued)

\[ 1 \text{ mol of } \text{H}_2\text{O} = 6.022 \text{ molecules of } \text{H}_2\text{O} \]

\[ 1 \text{ mol } \text{H}_2\text{O} \quad \text{and} \quad 6.022 \times 10^{23} \text{ H}_2\text{O molecules} \]

\[ 6.022 \text{ H}_2\text{O molecules} \quad 1 \text{ mol } \text{H}_2\text{O} \]

STEP 4 Set Up Problem

\[ 24.0 \text{ g } \text{H}_2\text{O} \times \frac{1 \text{ mol } \text{H}_2\text{O}}{18.02 \text{ g } \text{H}_2\text{O}} \]

\[ \times 6.022 \times 10^{23} \text{ H}_2\text{O molecules} \]

\[ \times \frac{1 \text{ mol } \text{H}_2\text{O}}{1 \text{ mol } \text{H}_2\text{O}} \]

\[ = 8.02 \times 10^{23} \text{ H}_2\text{O molecules} \quad (3) \]