MOLECULAR MASS AND FORMULA MASS

**Molecular mass** = sum of the atomic weights of all atoms in the molecule.

**Formula mass** = sum of the atomic weights of all atoms in the formula unit.
MOLECULAR MASS AND FORMULA MASS

- Ammonium sulfate, $(\text{NH}_4)_2\text{SO}_4$
- Magnesium perchlorate, $\text{Mg(ClO}_4)_2$
- Carbon tetrachloride, $\text{CCl}_4$
- Diphosphorus pentoxide, $\text{P}_2\text{O}_5$
16.00 amu + 12.01 amu + 16.00 amu = 44.01 amu
Counting Atoms

Chemistry is a quantitative science—we need a “counting unit.”

**MOLE**

1 mole is the amount of substance that contains as many particles (atoms, molecules) as there are in 12.0 g of $^{12}$C.

518 g of Pb, 2.50 mol
Particles in a Mole

Avogadros Number

Amedeo Avogadro
1776-1856

\[6.0221415 \times 10^{23}\]

There is Avogadro’s number of particles in a mole of any substance.
MOLECULAR MASS AND MOLAR MASS

Molecular mass = sum of the atomic weights of all atoms in the molecule.

Molar mass = molecular weight in grams
Molar Mass

1 mol of $^{12}$C
= 12.00 g of C
= 6.022 x $10^{23}$ atoms of C

12.00 g of $^{12}$C is its **MOLAR MASS**

Taking into account all of the isotopes of C, the molar mass of C is **12.011 g/mol**
One-mole Amounts

- Sulfur: 32.066 g
- Magnesium: 24.305 g
- Tin: 118.71 g
- Silicon: 28.086 g

Copper: 63.546 g
PROBLEM: What amount of Mg is represented by 0.200 g? How many atoms?

Mg has a molar mass of 24.3050 g/mol.

\[
0.200 \text{ g} \left( \frac{1 \text{ mol}}{24.31 \text{ g}} \right) = 8.23 \times 10^{-3} \text{ mol}
\]

How many atoms in this piece of Mg?

\[
8.23 \times 10^{-3} \text{ mol} \left( \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} \right) = 4.95 \times 10^{21} \text{ atoms Mg}
\]
What is the molar mass of ethanol, \( \text{C}_2\text{H}_6\text{O} \)?

1 mol contains

- 2 mol C (12.01 g C/1 mol) = 24.02 g C
- 6 mol H (1.01 g H/1 mol) = 6.06 g H
- 1 mol O (16.00 g O/1 mol) = 16.00 g O

TOTAL = molar mass = 46.08 g/mol
• **Formula =** $C_8H_9NO_2$

• **Molar mass =** 151.2 g/mol
Molar Mass

Note that the mass of water is included in the molar mass of a compound.

Aspirin, $C_9H_8O_4$, 180.2 g/mol
Copper(II) chloride dihydrate, $CuCl_2 \cdot 2H_2O$, 170.5 g/mol
Iron(III) oxide, $Fe_2O_3$, 159.7 g/mol

$H_2O$, 18.02 g/mol
Percent Composition

• Percent composition is the percentage by mass of each element in the compound.

• \( \%A = \frac{\text{mass of } A}{\text{mass of compound}} \times 100 \)

• Sum of percentages should equal 100
A pure compound always consists of the same elements combined in the same proportions by weight.

Therefore, we can express molecular composition as **PERCENT BY WEIGHT**

**Ethanol, C₂H₆O**
- 52.13% C
- 13.15% H
- 34.72% O
Percent Composition

Consider NO\textsubscript{2}, Molar mass = ?

What is the weight percent of N and of O?

Wt. % N = \( \frac{14.0 \text{ g N}}{46.0 \text{ g NO}_2} \times 100\% = 30.4\% \)

Wt. % O = \( \frac{2(16.0 \text{ g O per mol NO}_2)}{46.0 \text{ g NO}_2} \times 100\% = 69.6\% \)

What are the weight percentages of N and O in NO?
Determining Formulas

In chemical analysis we determine the % by weight of each element in a given amount of pure compound and derive the empirical or simplest formula.

PROBLEM: A compound of B and H is 81.10% B. What is its empirical formula?
A compound of B and H is 81.10% B. What is:

• Because it contains only B and H, it must contain 18.90% H.

• In 100.0 g of the compound there are 81.10 g of B and 18.90 g of H.

• Calculate the number of moles of each constituent.
A compound of B and H is 81.10% B. What is

Calculate the number of moles of each element in 100.0 g of sample.

\[
\begin{align*}
81.10 \text{ g B} \left( \frac{1 \text{ mol}}{10.81 \text{ g}} \right) &= 7.502 \text{ mol B} \\
18.90 \text{ g H} \left( \frac{1 \text{ mol}}{1.008 \text{ g}} \right) &= 18.75 \text{ mol H}
\end{align*}
\]
A compound of B and H is 81.10% B. What is

Take the ratio of moles of B and H. **Always divide by the smaller number.**

\[
\frac{18.75 \text{ mol H}}{7.502 \text{ mol B}} = \frac{2.499 \text{ mol H}}{1.000 \text{ mol B}} = \frac{2.5 \text{ mol H}}{1.0 \text{ mol B}}
\]

But we need a whole number ratio.

2.5 mol H/1.0 mol B = 5 mol H to 2 mol B

**EMPIRICAL FORMULA** = \( \text{B}_2\text{H}_5 \)
A compound of B and H is 81.10% B. Its empirical formula is $\text{B}_2\text{H}_5$. What is Is the molecular formula $\text{B}_2\text{H}_5$, $\text{B}_4\text{H}_{10}$, $\text{B}_6\text{H}_{15}$, $\text{B}_8\text{H}_{20}$, etc.? $\text{B}_2\text{H}_6$ is one example of this class of compounds.
A compound of B and H is 81.10% B. Its empirical formula is B4H10.

We need to do an experiment to find the molar mass.

Here experiment gives 53.3 g/mol.

Compare with the mass of B2H5:

\[ \frac{53.3 \text{ g/mol}}{26.66 \text{ g/unit of } B_2H_5} = \frac{2 \text{ units of } B_2H_5}{1 \text{ mol}} \]

Molecular formula = B4H10
The Empirical Formula

A sample is made up of 1.61 g P and 2.98 g F. Find the EF.

Determine the masses of each element:

\[
\begin{align*}
1.61 \text{ g P} & \quad 2.98 \text{ g F} \\
\end{align*}
\]

Convert the masses into moles of each element:

\[
\begin{align*}
1.61 \text{ g P} & \times \frac{1 \text{ mol P}}{30.97 \text{ g P}} = 0.0520 \text{ mol P} \\
2.98 \text{ g F} & \times \frac{1 \text{ mol F}}{19.00 \text{ g F}} = 0.157 \text{ mol F}
\end{align*}
\]

Express the moles as the smallest possible ratio:

\[
\begin{align*}
\frac{0.0520}{0.0520} & = 1.00 \\
\frac{0.157}{0.0520} & = 3.02
\end{align*}
\]

Write the EF using the values above as subscripts:

\[
\text{PF}_3
\]
The Empirical Formula

A compound is found to contain 20.0% carbon, 2.2% hydrogen and 77.8% chlorine. Determine the EF.

Determine the masses of each element assuming 100 g:

- 20.0 g C
- 2.2 g H
- 77.8 g Cl

Convert the masses into moles of each element:

\[
20.0 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 1.67 \text{ mol C}
\]

\[
2.2 \text{ g H} \times \frac{1 \text{ mol H}}{1.008 \text{ g H}} = 2.18 \text{ mol H}
\]

\[
77.8 \text{ g Cl} \times \frac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 2.19 \text{ mol Cl}
\]

Express the moles as the smallest possible ratio:

\[
\frac{1.67}{1.67} = 1.00 \quad \frac{2.18}{1.67} = 1.30 \quad \frac{2.19}{1.67} = 1.30
\]

Write the EF using the values above as subscripts:

\[\text{CH}_{1.3}\text{Cl}_{1.3} = \text{C}_3\text{H}_4\text{Cl}_4\]

Must have a whole number ratio!
The Molecular Formula
Fructose is found to contain 40.0 % carbon, 6.71 % hydrogen and the rest oxygen. The molar mass of fructose is 180.16 g/mol. Determine the EF and molecular formula.

Determine the masses of each element assuming 100 g:
40.0 g C  6.71 g H  53.29 g O

Convert the masses into moles of each element:

\[
\frac{40.0 \text{ g C}}{12.01 \text{ g C}} \times \frac{1 \text{ mol C}}{1 \text{ mol C}} = 3.33 \text{ mol C}
\]

\[
\frac{6.71 \text{ g H}}{1.008 \text{ g H}} \times \frac{1 \text{ mol H}}{1 \text{ mol H}} = 6.66 \text{ mol H}
\]

\[
\frac{53.29 \text{ g O}}{16.00 \text{ g O}} \times \frac{1 \text{ mol O}}{1 \text{ mol O}} = 3.33 \text{ mol O}
\]

Express the moles as the smallest possible ratio:
\[
\text{CH}_2\text{O}
\]
The Molecular Formula

Fructose is found to contain 40.0 % carbon, 6.71 % hydrogen and the rest oxygen. The molar mass of fructose is 180.16 g/mol. Determine the EF and molecular formula.

Determine the mass of the EF (CH₂O):

\[ 12.01 \text{ g/mol} + 2(1.008 \text{ g/mol}) + 16 \text{ g/mol} = 30.03 \text{ g/mol} \]

Determine the number of EF units in the molecule:

\[
\frac{\text{Molar mass compound}}{\text{Molar mass EF}} = \frac{180.16 \text{ g/mol}}{30.03 \text{ g/mol}} = 6
\]

Write the molecular formula:

\[ (\text{CH}_2\text{O})_6 = \text{C}_6\text{H}_{12}\text{O}_6 \]
DETERMINE THE FORMULA OF A COMPOUND OF Sn AND I

Sn(s) + some I₂(s) → SnIₓ
Data to Determine the formula of a Sn—I Compound

- Reaction of Sn and I₂ is done using excess Sn.
- Mass of Sn in the beginning = 1.056 g
- Mass of iodine (I₂) used = 1.947 g
- Mass of Sn remaining = 0.601 g
Tin and Iodine Compound

Find the mass of Sn that combined with 1.947 g I₂.

Mass of Sn initially = 1.056 g
Mass of Sn recovered = 0.601 g
Mass of Sn used = 0.455 g

Find moles of Sn used:

\[
0.455 \text{ g Sn} \left( \frac{1 \text{ mol}}{118.7 \text{ g}} \right) = 3.83 \times 10^{-3} \text{ mol Sn}
\]
Tin and Iodine Compound

Now find the number of moles of I\(_2\) that combined with 3.83 \times 10^{-3} \text{ mol Sn. Mass of I}_2 \text{ used was 1.947 g.}

\[
1.947 \text{ g I}_2 \left( \frac{1 \text{ mol I}_2}{253.81 \text{ g I}_2} \right) = 7.671 \times 10^{-3} \text{ mol I}_2
\]

How many mol of iodine atoms?

\[
7.671 \times 10^{-3} \text{ mol I}_2 \left( \frac{2 \text{ mol I \text{ atoms}}}{1 \text{ mol I}_2} \right) \]

\[
= 1.534 \times 10^{-2} \text{ mol I \text{ atoms}}
\]
Tin and Iodine Compound

Now find the ratio of number of moles of moles of I and Sn that combined.

\[
\frac{1.534 \times 10^{-2} \text{ mol I}}{3.83 \times 10^{-3} \text{ mol Sn}} = \frac{4.01 \text{ mol I}}{1.00 \text{ mol Sn}}
\]

Empirical formula is \(\text{SnI}_4\)
Percent Composition

If you know the percent composition of a compound, you can find the amount of any element in a known amount of the compound.

How many g of potassium are in 154.6 g of K$_2$S? (MW = 110.26 g/mol)

**Method 1:**

\[
\frac{154.6 \text{ g } K_2S \times 78.2 \text{ g K}}{110.26 \text{ g } K_2S} = 109.6 \text{ g K}
\]

**Method 2:**

Use the percent composition as a conversion factor, g K/100 g K$_2$S

\[
\frac{154.6 \text{ g } K_2S \times 70.92 \text{ g K}}{100 \text{ g } K_2S} = 109.6 \text{ g K}
\]

Both methods are equally valid!
Avogadro’s Number: Use it Wisely!

How many molecules of CO$_2$ are in 123.4 g of CO$_2$?

$$
123.4 \, \text{g CO}_2 \times \frac{1 \, \text{mol CO}_2}{44.01 \, \text{g CO}_2} \times \frac{6.02 \times 10^{23} \, \text{molecules CO}_2}{1 \, \text{mol CO}_2} = 1.69 \times 10^{24} \, \text{molecules CO}_2
$$

How many O atoms are in 123.4 g of CO$_2$?

$$
123.4 \, \text{g CO}_2 \times \frac{1 \, \text{mol CO}_2}{44.01 \, \text{g CO}_2} \times \frac{6.02 \times 10^{23} \, \text{molecules CO}_2}{1 \, \text{mol CO}_2} \times \frac{2 \, \text{O atoms}}{1 \, \text{molecule CO}_2} = 3.37 \times 10^{24} \, \text{O atoms}
$$

compounds convert directly to molecules

elements convert directly to atoms

compounds to atoms take an extra step!
Avogadro’s Number: Use it Wisely!

How many total atoms are in 4.5 g of $\text{H}_2\text{SO}_4$?

$$
\frac{4.5 \text{ g } \text{H}_2\text{SO}_4}{98.06 \text{ g } \text{H}_2\text{SO}_4} \times \frac{1 \text{ mol } \text{H}_2\text{SO}_4}{1 \text{ mol } \text{H}_2\text{SO}_4} \times \frac{6.02 \times 10^{23} \text{ mcs } \text{H}_2\text{SO}_4}{1 \text{ mol } \text{H}_2\text{SO}_4} \times \frac{7 \text{ atoms}}{1 \text{ mc } \text{H}_2\text{SO}_4}
$$

$$= 1.93 \times 10^{23} \text{ atoms}$$

How many H atoms are in 4.5 g of $\text{H}_2\text{SO}_4$?

$$
\frac{4.5 \text{ g } \text{H}_2\text{SO}_4}{98.06 \text{ g } \text{H}_2\text{SO}_4} \times \frac{1 \text{ mol } \text{H}_2\text{SO}_4}{1 \text{ mol } \text{H}_2\text{SO}_4} \times \frac{6.02 \times 10^{23} \text{ mcs } \text{H}_2\text{SO}_4}{1 \text{ mol } \text{H}_2\text{SO}_4} \times \frac{2 \text{ H atoms}}{1 \text{ mc } \text{H}_2\text{SO}_4}
$$

$$= 5.53 \times 10^{22} \text{ H atoms}$$

A question using this concept will be on the exam!!!
Practice Problems: Molar Mass

1. Find the molar mass of the following compounds:
   a. $\text{C}_3\text{H}_7\text{OH}$
   b. cobalt(III) bromide
   c. silicon dioxide
   d. $\text{C}_8\text{H}_9\text{NO}_2$ (active ingredient in Tylenol)

2. Find the number of moles of each substance:
   a. 11.23 g iodine
   b. 3.32 g beryllium nitrate
   c. 0.477 g $\text{C}_9\text{H}_{20}$
   d. 659 g $\text{C}_2\text{H}_5\text{OH}$
Practice Problems: Avogadro’s # 35

Find the number of grams in the following compounds:

a. $4.30 \times 10^{22}$ molecules of $\text{C}_6\text{H}_{14}$

b. $6.77 \times 10^{24}$ atoms of aluminum

c. 5.445 moles of ammonium hydroxide
Practice Problems: Mass Relationship

1. Potassium sulfate is found in some fertilizers as a source of potassium. How many grams of potassium can be obtained from 143.6 g of the compound?

Practice Problems: Percent Composition

1. Calculate the percent composition of each compound:

a. octane (C₈H₁₈)
b. aluminum acetate
c. calcium dihydrogen phosphate
d. chromium(II) chloride
Practice Problems: Empirical Formula

1. A compound is found to contain 63 % manganese and 37 % oxygen. Find the empirical formula of the compound.

2. A compound contains 42.05 g of nitrogen and 95.95 g of oxygen. Find its empirical formula.

3. A compound has 68.85 % carbon, 4.95 % hydrogen and 26.20 % oxygen and has a molar mass of 366 g/mol. What is the empirical formula for this compound? What is the molecular formula?