Counting Atoms

- Mg burns in air (O₂) to produce white magnesium oxide, MgO.
- How can we figure out how much oxide is produced from a given mass of Mg?

Molar Mass

Reminder:
The molar mass (also called atomic weight) for each element is found on the periodic table.

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Symbol</th>
<th>Atomic Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Mg</td>
<td>24.3050</td>
</tr>
</tbody>
</table>

So the magnesium found on earth weighs 24.31 grams for each mole.
PROBLEM: If 0.200 g of Mg is burned, how much MgO is formed?

Mg has a molar mass of 24.3050 g/mol.

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

That means that \(8.23 \times 10^{-3}\) mol of MgO is formed and is composed of \(8.23 \times 10^{-3}\) mol of Mg and \(8.23 \times 10^{-3}\) mol of O.

\[
8.23 \times 10^{-3} \text{ mol of O has a mass of } (8.23 \times 10^{-3} \text{ mol}) \times (16.0 \text{ g/mol}) = 0.132 \text{ g}.\]

So the mass of MgO is 0.332 g

Notice that I use unit analysis.

MOLAR MASS AND MOLECULAR WEIGHT

• The molar mass of a molecule is the sum of the atomic weights of all atoms in the molecule.

• This is sometimes called molecular weight.

• To calculate molar mass of a molecule, simply add all molar masses of all the components.
What is the molar mass of ethanol, \( \text{CH}_3\text{CH}_2\text{OH} \)?

1 mol of ethanol contains

- 2 mol C (12.01 g /mol C) = 24.02 g C
- 6 mol H (1.01 g /mol H) = 6.06 g H
- 1 mol O (16.00 g /mol O) = 16.00 g O
- TOTAL = molar mass = 46.08 g/mol

How many moles of alcohol are there in a “standard” can of beer if it contains 21.3 g of \( \text{CH}_3\text{CH}_2\text{OH} \)?

(a) Molar mass of \( \text{CH}_3\text{CH}_2\text{OH} \) = 46.08 g/mol  
(b) Calculate the moles of alcohol 

\[
\frac{21.3 \text{ g}}{46.08 \text{ g/mol}} = 0.462 \text{ mol}
\]

(c) Notice the units — they show by cancellation how to write the equation.
How many **molecules** of alcohol are there in a “standard” can of beer if it contains 21.3 g of CH₃CH₂OH?

We know there are 0.462 mol of CH₃CH₂OH.

\[
0.462 \text{ mol} \times \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mol}} = 2.78 \times 10^{23} \text{ molecules}
\]

How many **atoms of C** are there in the ethanol in a “standard” can of beer?

We know there are 2.78 x 10²³ molecules of ethanol.

Each molecule contains 2 C atoms.

Therefore, the number of C atoms is

\[
2.78 \times 10^{23} \text{ molecules} \times \frac{2 \text{ C atoms}}{1 \text{ molecule}} = 5.56 \times 10^{23} \text{ C atoms}
\]
Empirical and Molecular Formulas

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, $C_2H_6O$, is 52.13% C, 13.15% H and 34.72% O by weight

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Empirical and Molecular Formulas

Why? The molar mass of ethanol is 46.08 g/mol. Of that mass, the amount due to carbon is 24.02 g/mol, that due to hydrogen is 6.06 g/mol and that due to oxygen is 16.00 g/mol.

For C, $24.03/46.08 = 52.13\%$
For H, $6.06/46.08 = 13.15\%$
For O, $16.00/46.08 = 34.72\%$

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Percent Composition

Consider NO₂

What is the weight percent of N and of O in NO₂?

\[
M = 1 \cdot 14.0 \text{ g/mol} + 2 \cdot 16.0 \text{ g/mol} = 46.0 \text{ g/mol}
\]

\[
\text{Wt. % N} = \frac{14.0 \text{ g N/mol}}{46.0 \text{ g NO₂/mol}} \times 100\% = 30.4\%
\]

\[
\text{Wt. % O} = \frac{2(16.0 \text{ g O/mol})}{46.0 \text{ g NO₂/mol}} \times 100\% = 69.6\%
\]

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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 by weight. What is its empirical formula?

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

First some logic:

- Because the compound 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.

Now use this to calculate the number of moles of each constituent in this amount of compound.

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

\[
\begin{align*}
81.10 \text{ g B} & \cdot \frac{1 \text{ mol}}{10.81 \text{ g}} = 7.502 \text{ mol B} \\
18.90 \text{ g H} & \cdot \frac{1 \text{ mol}}{1.008 \text{ g}} = 18.75 \text{ mol H}
\end{align*}
\]

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

Now, recognize that atoms combine in the ratio of small whole numbers. For example, for boron trihydride:

1 atom B + 3 atoms H → 1 molecule BH₃

or

1 mol B atoms + 3 mol H atoms → 1 mol BH₃ molecules

Now find the ratio of moles of elements in our compound.

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

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

\[
\begin{align*}
\frac{18.75 \text{ mol H}}{7.502 \text{ mol B}} &= \frac{2.499 \text{ mol H}}{1.000 \text{ mol B}} = \frac{2.5 \text{ mol H}}{1.0 \text{ mol B}}
\end{align*}
\]

But we need a whole number ratio.

\[
2.5 \text{ mol H} / 1.0 \text{ mol B} = 5 \text{ mol H} / 2 \text{ mol B}
\]

EMPIRICAL FORMULA = B₂H₅
A compound of B and H is 81.10% B. What is its empirical formula?

What is its **molecular formula**?

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.?

To determine this we need to know the molar mass.

In this case, the molar mass (or molecular weight) is **53.3 g/mol**.

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

What is its **molecular formula**?

Compare this value, 53.3 g/mol with the mass of $\text{B}_2\text{H}_5 = 26.66$ g/unit (the smallest possible unit with a 2:5 ratio).

Now find the ratio of these masses.

\[
\frac{53.3 \text{ g/mol}}{26.66 \text{ g/unit of } \text{B}_2\text{H}_5} = \frac{2 \text{ units of } \text{B}_2\text{H}_5}{1 \text{ mol}}
\]

**Molecular formula** = $\text{B}_4\text{H}_{10}$
What is the percent weight of N in this compound?

- Formula = $C_8H_9NO_2$
- Molar mass = 151.2 g/mol