Chapter 6. Chemical Calculations: Formula Masses, Moles, and Chemical Equations
6.1 Formula Masses

Chemical Formula

A chemical formula is a way of showing information about the atoms/ions that make up a particular chemical compound. The subscripts in the chemical formula indicate the number of each type and the ratio of the atoms/ions of each element in the chemical formula.

Ionic compounds

The subscripts in the chemical formula of an ionic compound indicate the ratio of the ions formed by each element in the chemical formula. For ionic compound chemical formula is always empirical formula (simple ratio of ion in the formula). These concepts were introduced in the chapter 4. For example:

a) Calcium oxide, a simple ionic solid consisting of one calcium ion, Ca\(^{2+}\) and one oxide ion, O\(^{2-}\) has the chemical formula: CaO not Ca\(_2\)O\(_2\).

b) Calcium chloride, a simple ionic solid consisting of one calcium ion, Ca\(^{2+}\) and two chloride ions, 2Cl\(^{-}\) has the chemical formula: CaCl\(_2\).

c) Sodium sulfate with two sodium ions, 2Na\(^{+}\) and one sulfate ion, (SO\(_4\))\(^{2-}\) has the chemical formula: Na\(_2\)SO\(_4\).

Covalent compounds

a) The subscripts in the chemical formula of an covalent compound indicate the type and ratio of the atoms of each element in the chemical formula. For covalent compound, a compound made up of two or more non-metal combinations, chemical formula is also called the molecular formula. It lists the element by its chemical symbol and subscript indicating the number of atoms of each element. These concepts were introduced in the chapter 5.

For example:

b) Methane, a simple molecule consisting of one carbon atom bonded to four hydrogen atoms, has the chemical formula: CH\(_4\).

c) Glucose with six carbon atoms, twelve hydrogen atoms and six oxygen atoms has the chemical formula: C\(_6\)H\(_{12}\)O\(_6\). This idea was introduced in the chapter 5.

Formula mass

Formula mass is a number expressed in amu or g/mol units obtained by simply adding up all masses of the atoms that are in the chemical formula. This calculation is based on the idea that mass of atoms is neither created nor destroyed when several atoms react.
to form a compound (the law of conservation of mass). Therefore we count up the number of atoms of each type in the formula, and add up the total mass. Examples of formula mass calculations are given below.

### Calculating formula masses

#### Examples of calculations of the formula mass ionic compounds?

<table>
<thead>
<tr>
<th>Formula</th>
<th>Na₂CO₃</th>
<th>NH₄Cl</th>
<th>Al₂(SO₄)₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>2 x 22.99 = 45.98</td>
<td>N = 1 x 14.01 = 14.01</td>
<td>Al = 2 x 26.98 = 53.96</td>
</tr>
<tr>
<td>C = 1 x 12.01 = 12.01</td>
<td>H = 4 x 1.01 = 4.04</td>
<td>S = 3 x 32.07 = 96.21</td>
<td></td>
</tr>
<tr>
<td>O = 3 x 16.00 = 48.00</td>
<td>Cl = 1 x 35.45 = 35.45</td>
<td>O = 12 x 16.00 = 192.00</td>
<td></td>
</tr>
<tr>
<td>(Formula mass) 105.99</td>
<td>(Formula mass) 53.50</td>
<td>(Formula mass) 342.17</td>
<td></td>
</tr>
</tbody>
</table>

Calculate the formula mass of the following ionic compounds:

**a)** NaCl, **b)** K₂CO₃, and **c)** Fe₂(CO₃)₃.

**Answers:**

a) NaCl (58.45 g/mol), b) K₂CO₃ (138.2 g/mol) and c) Fe₂(CO₃)₃ (294.73 g/mol)

#### Examples of calculations of the formula mass covalent compounds?

<table>
<thead>
<tr>
<th>Formula</th>
<th>H₃PO₄</th>
<th>H₂SO₄</th>
<th>C₆H₁₂O₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺</td>
<td>3 x 1.01 = 3.03</td>
<td>H = 3 x 1.01 = 3.03</td>
<td>C = 6 x 12.01 = 72.06</td>
</tr>
<tr>
<td>P = 1 x 30.97 = 30.97</td>
<td>S = 1 x 32.07 = 32.07</td>
<td>H = 12 x 1.01 = 12.12</td>
<td></td>
</tr>
<tr>
<td>O = 4 x 16.00 = 64.00</td>
<td>O = 4 x 16.00 = 64.00</td>
<td>O = 6 x 16.00 = 96.00</td>
<td></td>
</tr>
<tr>
<td>(Formula mass) 98.00</td>
<td>(Formula mass) 99.10</td>
<td>(Formula mass) 180.18</td>
<td></td>
</tr>
</tbody>
</table>

**Practice Problems:** Calculate the molecular mass or formula mass of each of the following compounds.

a) SO₃  b) KBrO₃  c) CaSO₄  d) (NH₄)₃PO₄  e) Fe(NO₃)₃  f) C₂H₅NO₂  g) MgS₂O₃

**Answers**

a) SO₃ (80.1 g/mol) b) KBrO₃ (167.2 g/mol) c) CaSO₄ (136.2 g/mol)

d) (NH₄)₃PO₄ (149 g/mol) e) Fe(NO₃)₃ (241.8 g/mol)  f) C₂H₅NO₂ (75 g/mol)  g) MgS₂O₃ (136.5 g/mol)

### 6.2 The Mole: A Counting Unit for Chemists

#### Amount of Substance-The mole

Chemical equations are written in terms of ions or atoms. However, we cannot pick ions/atoms individually and do chemical reactions since they are too small. Therefore we always have to use measurable quantities usually in grams as the amounts. To check if we are using proper numbers/ratios of atoms or ions we need a conversion factor to convert grams to atoms represented the stoichiometric coefficients in the chemical equation. Mole is a convenient conversion factor that we use to convert between atoms and grams.

**The Mole**

Mole is a convenient number (6.022 x 10²³) to convert grams into number of atoms or vice versa. Mole is also called the Chemist’s dozen since it brings atomic particles to a sample size that could handle easily similar/analogy to dozen of eggs.
Avogadro's Number

The name "Avogadro's Number" is just an honorary name attached to the mole when units used are in grams and amu. Avogadro's number is $6.022 \times 10^{23}$.

6.3 The Mass of a Mole

Gram mole: A gram mole of a substance is the formula mass in grams of a pure chemical. In a gram mole of any chemical substance there are $6.022 \times 10^{23}$ formula units of the compound. Of course, if we used some other mass unit defined the mole such as "pound mole", the "number" would be different than $6.022 \times 10^{23}$.

In a lab the atoms and molecules are weighed in grams even though in the periodic table atomic mass are reported in amu or g/mol. However, if you take atomic mass in grams the number of atoms is simply $6.022 \times 10^{23}$. In other words gram atomic weight or gram molecular weight contains $6.022 \times 10^{23}$ atoms or molecules. This number is called Avogadro's number or mole of particles. (simply the mole).

6.4 Chemical Formulas and the Mole Concept

Molar mass

Molar mass is defined as the amount of mass of a chemical substance when formula mass is taken grams. For Example, molar mass of C$_6$H$_{12}$O$_6$ is 180.18 g since Formula mass of C$_6$H$_{12}$O$_6$ is 180.18 g/mole. Molar mass contains mole ($6.022 \times 10^{23}$) of formula (C$_6$H$_{12}$O$_6$) units.

The atomic mass of sodium is 23.0 amu and molar mass is 23.0 g/mol

1 molar mass equals one mole. This gives a convention for creating conversion factors to convert grams to moles.

$$\frac{23.0 \text{ g sodium}}{1 \text{ mole sodium}} \text{ or } \frac{1 \text{ mole sodium}}{23.0 \text{ g sodium}}$$

Important conversion factors used in chemical stiochiometry.

<table>
<thead>
<tr>
<th>1 amu = 1 g/mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 amu = 1 g/6.022 x $10^{23}$</td>
</tr>
<tr>
<td>1 g = 6.022 x $10^{23}$ amu</td>
</tr>
<tr>
<td>6.022 x $10^{23}$ atoms C = 12.01 grams of carbon (C)</td>
</tr>
</tbody>
</table>

**Atoms**

gram atomic weight = $6.022 \times 10^{23}$ atoms

12.01 g of C = $6.022 \times 10^{23}$ atoms

**Molecules**

gram molecular weight = $6.022 \times 10^{23}$ atoms

182.02 g of H$_2$O = $6.022 \times 10^{23}$ H$_2$O molecules

182.02 g of H$_2$O = 2 x $6.022 \times 10^{23}$ H atoms

182.02 g of H$_2$O = 1 x $6.022 \times 10^{23}$ OH atoms
### Ionic compounds

Molar mass = $6.022 \times 10^{23}$ formula units

<table>
<thead>
<tr>
<th>Grams Formula mass</th>
<th>$6.022 \times 10^{23}$ Na$_2$CO$_3$ formula units</th>
</tr>
</thead>
<tbody>
<tr>
<td>105.99 g of Na$_2$CO$_3$</td>
<td>$2 \times 6.022 \times 10^{23}$ Na$^+$ ions</td>
</tr>
<tr>
<td>105.99 g of Na$_2$CO$_3$</td>
<td>$1 \times 6.022 \times 10^{23}$ Cl$^-$ ions</td>
</tr>
</tbody>
</table>

### Covalent compounds

Molar mass = $6.022 \times 10^{23}$ molecules

<table>
<thead>
<tr>
<th>Grams Formula mass</th>
<th>$6.022 \times 10^{23}$ C$<em>6$H$</em>{12}$O$_6$ molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>180.18 g of C$<em>6$H$</em>{12}$O$_6$</td>
<td>$6 \times 12.01$ g C atoms</td>
</tr>
<tr>
<td>180.18 g of C$<em>6$H$</em>{12}$O$_6$</td>
<td>$12 \times 1.01$ g H atoms</td>
</tr>
<tr>
<td>180.18 g of C$<em>6$H$</em>{12}$O$_6$</td>
<td>$6 \times 16.00$ g O atoms</td>
</tr>
</tbody>
</table>

---

### Grams to moles calculations

#### a) How many moles of iron (Fe) are present in 180.1 g of elemental iron?

a.w. Fe = 55.85 g/mol

This is a problem to convert grams to moles. Conversion factor is $\frac{55.85 \text{ g Fe}}{1 \text{ mol}}$.

\[
\frac{180.1 \text{ g Fe}}{55.85 \text{ g Fe}} \times \frac{1 \text{ mol}}{} = 3.225 \text{ mol Fe}
\]

#### b) How many moles of K$_2$SO$_4$ are present in 180.1 g of potassium sulfate?

Formula mass (K$_2$SO$_4$) = 174.26 g/mol

This is a problem to convert g to moles.

Using factor label method:

\[
\frac{180.1 \text{ g K}_2\text{SO}_4}{174.26 \text{ g K}_2\text{SO}_4} \times \frac{1 \text{ mol K}_2\text{SO}_4}{1} = 1.033 \text{ mol K}_2\text{SO}_4
\]

### Moles to grams calculations

#### a) How many grams are in 4.61 mol AlCl$_3$?

Formula mass (AlCl$_3$) = 133.5 g/mol, Conversion factor is $\frac{133.5 \text{ g AlCl}_3}{1 \text{ mol AlCl}_3}$.

\[
\frac{4.61 \text{ mol AlCl}_3}{1} \times \frac{133.5 \text{ g AlCl}_3}{1 \text{ mol AlCl}_3} = 615.5 \text{ g AlCl}_3
\]

#### b) How many grams are in 0.158 mol IF$_5$?

Formula mass (IF$_3$) = 220.0 g/mol, Conversion factor is $\frac{220.0 \text{ g IF}_5}{1 \text{ mol IF}_5}$

\[
\frac{0.158 \text{ mol IF}_5}{1} \times \frac{220.0 \text{ g IF}_5}{1 \text{ mol IF}_5} = 35.1 \text{ g IF}_5
\]

### Moles to numbers of atoms calculations

#### How many sulfur atoms are in 5.00 moles of sulfur?

Conversion factor 1 mole S atoms = $6.022 \times 10^{23}$ S atoms

\[
\frac{5.00 \text{ mol S}}{1} \times \frac{6.022 \times 10^{23} \text{ S atoms}}{1 \text{ mol S}} = 3.00 \times 10^{24} \text{ S atoms}
\]
5

**Mass of atoms in grams**

**What is the mass of $7.5 \times 10^5$ atoms of Cu in grams?**

This problem requires conversion of atoms to grams. If you remember correctly this is the definition of the mole. $1 \text{ mol} = 63.55 \text{g Cu} = \text{gram atomic weight}$

$1 \text{ mol} = 6.022 \times 10^{23} \text{ Cu atoms} = 63.55 \text{ grams Cu}$

Therefore,

$$
\frac{7.5 \times 10^5 \text{ Cu atoms}}{6.022 \times 10^{23} \text{ Cu atom}} \times 63.55 \text{ g Cu} = 7.9 \times 10^{-17} \text{ g Cu}
$$

6.5 The Mole and Chemical Calculations

When a chemical reaction occurs, it can be described by an equation. A chemical calculations starts with a chemical equation (reaction) which gives formulas of starting and final substances maintaining atomic balance using coefficients that gives the moles of reactants and products represented by their names or by their chemical symbols. In order to use chemical equations in calculations you need to know the information that can be extracted from them.

**Chemical Equations**: An equation with coefficients and chemical formulas showing the starting and final substances while maintaining atomic balance.

**Rules for writing chemical equation.**

1. Set down the formula(s) for any substance entering into the reaction. Place a + sign between the formulas as needed and put the yield arrow ($\rightarrow$) after the last one.
2. Write down the correct formulas for all products formed, placing them to the right of the arrow.
3. Reaction should be **balanced** as described later in section 6.6.

**What is in a chemical Equation:**

1. **Left side shows the reactants** which enter into a reaction.
2. **Right side shows the products** which are formed by the reaction.
3. **Physical sate of chemicals** in parenthesis after the chemicals: (g) for gases, (l) for liquids, (s) for solids, (aq) for water (aqueous) solutions. Most often we drop this information since they are not important for the gram to mole conversions.
4. **Stoichiometric Coefficients**: The large numbers in front of the chemical formulas that gives the amounts (moles) of each substance used and each substance produced.
5. **Thermochemical data** $\Delta H$: A negative value indicates (exothermic (-)) that heat given out and positive value an endothermic(+) heat absorbed. If this data is included in the chemical reaction the physical state of reactants also should be given and the chemical equation is called a **thermochemical equation**.

**For example**: Hydrogen gas reacts with oxygen gas at 25°C burns to produce water (word description) Note that oxygen gas is diatomic, O$_2$. Most elements in the gas form are diatomic. This could be translated into a chemical equation through following steps:

$$
\text{Oxygen + Hydrogen } \rightarrow \text{water}
$$

O$_2$(g) + 2 H$_2$(g) $\rightarrow$ 2 H$_2$O(l); $\Delta H= -572 \text{ kJ}$

**Interpret the information conveyed by this chemical equation:**

**Reactants and products**: O$_2$ and H$_2$ are reactants and H$_2$O is the product.

**Stoichiometric and coefficients**: O$_2$, H$_2$ and H$_2$O has 1, 1 and 2, as their stoichiometric coefficients, respectively. They are used to get the mole conversion factors.

**Physical sate of chemicals**: O$_2$, H$_2$ are gases and H$_2$O is a liquid at 25°C.
Degree of reaction completion: O₂ and H₂ are completely (→) irreversibly converted to H₂O (if not equilibrium (⇔) where both reactants and products exists in a mixture).

Reaction conditions: reaction is done at 25°C without heating [if heated (Δ) or exposed to light (hν) sings are written on top of the arrow (→)].

Thermochemical data ΔH: 572 kJ of (exothermic (-)) heat given out per each 2mole of H₂ burned and 2mole of H₂O produced.

6.6 Writing and Balancing Chemical Equations

When you are writing chemical equations they should balanced. This mean the number of atoms of each type on each side (reactant and product) has to be equal. If the equation is not balanced it implies that you are either creating or destroying atoms of elements and this cannot be done by ordinary chemical reactions which should follow law of conservation of atoms/mass. Balancing is an application of the Law of conservation of mass (atoms) which states that in a chemical reaction atoms are neither created nor destroyed.

How many atoms of each element are indicated in one formula unit of each of the following?

<table>
<thead>
<tr>
<th>a) Al₂(C₂O₄)₃</th>
<th>b) Ca₃(PO₄)₂</th>
<th>c) 2 C₆H₁₂O₆</th>
<th>d) 3 Al₂(SO₄)₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Al atoms</td>
<td>3 Ca atoms</td>
<td>12 C atoms</td>
<td>6 Al atoms</td>
</tr>
<tr>
<td>6 C atoms</td>
<td>2 P atoms</td>
<td>24 H atoms</td>
<td>9 S atoms</td>
</tr>
<tr>
<td>12 O atoms</td>
<td>8 O atoms</td>
<td>12 O atoms</td>
<td>36 O atoms</td>
</tr>
</tbody>
</table>

Atomic balance in a chemical equation is achieved by changing coefficients, not subscripts. Chemical formula cannot be altered. Count the number of atoms of each type on each side (reactant and product) and if they are not equal equation need to be balanced. Polyatomic ions that are found on both reactant product sides are treated as a unit and are balanced as a whole.

Following steps are followed to ensure that a chemical equation is balances:

1. Pick the first elements to be balanced: Guide lines are finding the element with greatest number of atoms which is found just one compound on each side of the equation or fewer chemicals on the reactant and product side. [e.g. C₂H₆(g) + O₂(g) → CO₂(g) + H₂O(l), Hydrogen picked first then carbon and oxygen is balanced last]. Change the stoichiometric coefficients to balance the atoms of first element using a least common multiplier if not cross place subscripts on reactant and product side of the element.

2. Pick the second elements to be balanced: Next element greater number of atoms which are found only one chemical on the reactant and product side. Change the stoichiometric coefficients to balance atoms without changing coefficients of the first element.

3. Pick the third...fourth elements etc. until all elements are balanced.

4. Repeat step one, recount all Atoms and make sure atoms of each type on each side (reactant and product) and if they are equal chemical equation is balanced.
**Example:** Solid aluminum metal reacts with oxygen gas burns to produce solid white powder, aluminum oxide (word description). If we convert each of the chemical names into the appropriate symbols, we get the following:

Aluminium + Oxygen $\rightarrow$ Aluminium Oxide  
Aluminium-Al(s) + Oxygen- O$_2$(g) $\rightarrow$ Aluminium Oxide-Al$_2$O$_3$

This is the chemical equation for the burning of aluminium in oxygen.:  
$\text{Al} + \text{O}_2 \rightarrow \text{Al}_2\text{O}_3$

**Check the atomic balance:** Count the number of atoms on both sides

<table>
<thead>
<tr>
<th>Reactant side: Al + O$_2$</th>
<th>Product side: Al$_2$O$_3$</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Al atom</td>
<td>2 Al atoms</td>
<td>Reaction is not balanced.</td>
</tr>
<tr>
<td>2 O atoms</td>
<td>3 oxygen atom</td>
<td></td>
</tr>
</tbody>
</table>

**Step of 1 of balancing:** Pick the first element to be balanced...

<table>
<thead>
<tr>
<th>Reactant side: Al + O$_2$</th>
<th>Product side: Al$_2$O$_3$</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Al atom</td>
<td>2 Al atoms</td>
<td>Oxygen is first element to be balanced.</td>
</tr>
<tr>
<td>2 O atoms</td>
<td>3 oxygen atom</td>
<td></td>
</tr>
</tbody>
</table>

There is no “least common multiplier” for coefficients and need to cross place subscripts. Place subscripts of the O reactant side in the place of coefficient of reactant side and vise versa.

$\text{Al} + 3 \text{O}_2 \rightarrow 2 \text{Al}_2\text{O}_3$

<table>
<thead>
<tr>
<th>Reactant side: 1 Al atom 3 O atoms</th>
<th>Product side: 4 Al atom 6 O atoms</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Step of 2 of balancing:** Pick the seconds element to be balanced...

<table>
<thead>
<tr>
<th>Reactant side: Al + 3 O$_2$</th>
<th>Product side: 2 Al$_2$O$_3$</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Al atom</td>
<td>2 Al atoms</td>
<td>Aluminum is second element to be balanced.</td>
</tr>
<tr>
<td>2 O atoms</td>
<td>3 oxygen atom</td>
<td></td>
</tr>
</tbody>
</table>

Place 4 in the place of coefficient of reactant side.

$\text{Al} + 3 \text{O}_2 \rightarrow 2 \text{Al}_2\text{O}_3$

Balanced chemical equation:  $\text{Al (s)} + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{Al}_2\text{O}_3(\text{s})$

**Example:** Ethane is a gas burns in oxygen to give carbon dioxide gas and steam which is simply water in gaseous form and condenses to form water droplets. Here is the chemical equation rewritten with the chemical symbols:

Ethane- C$_2$H$_6$(g) + Oxygen- O$_2$(g) $\rightarrow$ Carbon Dioxide- CO$_2$(g) + water- H$_2$O(l)

C$_2$H$_6$(g) + O$_2$(g) $\rightarrow$ CO$_2$(g) + H$_2$O(l)

**Check the atomic balance:** Count the number of atoms on both sides

<table>
<thead>
<tr>
<th>Reactant side: C$_2$H$_6$ + O$_2$</th>
<th>Product side: CO$_2$ + H$_2$O</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 C atom</td>
<td>1 C atom</td>
<td>Reaction is not balanced.</td>
</tr>
<tr>
<td>6 H atoms</td>
<td>2 H atoms</td>
<td></td>
</tr>
<tr>
<td>2 O atoms</td>
<td>3 O atoms</td>
<td></td>
</tr>
</tbody>
</table>
**Step of 1 of balancing:** Pick the first element to be balanced...

<table>
<thead>
<tr>
<th>Reactant side: C₂H₆ + O₂</th>
<th>Product side: CO₂ + H₂O</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 H atoms</td>
<td>2 H atoms</td>
<td>Hydrogen is the first element to be balanced.</td>
</tr>
<tr>
<td>2 O atoms</td>
<td>3 O atoms</td>
<td></td>
</tr>
<tr>
<td>2 C atom</td>
<td>1 C atom</td>
<td></td>
</tr>
</tbody>
</table>

Multiply coefficient of H on product with 3 to balance H.

\[ \text{C}_2\text{H}_6 + \text{O}_2 \rightarrow \text{CO}_2 + 3 \text{H}_2\text{O} \]

<table>
<thead>
<tr>
<th>Reactant side: C₂H₆ + O₂</th>
<th>Product side: CO₂ + 3H₂O</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 H atoms</td>
<td>6 H atoms</td>
<td>Hydrogen is balanced.</td>
</tr>
<tr>
<td>4 C atom</td>
<td>4 C atom</td>
<td>Carbon is balanced.</td>
</tr>
<tr>
<td>2 O atoms</td>
<td>5 O atoms</td>
<td></td>
</tr>
</tbody>
</table>

**Step of 2 of balancing:** Pick the seconds element to be balanced...

<table>
<thead>
<tr>
<th>Reactant side: C₂H₆ + O₂</th>
<th>Product side: 2CO₂ + 3H₂O</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 H atoms</td>
<td>6 H atoms</td>
<td>Hydrogen is balanced.</td>
</tr>
<tr>
<td>2 C atom</td>
<td>2 C atom</td>
<td>Carbon is balanced.</td>
</tr>
<tr>
<td>7 O atoms</td>
<td>5 O atoms</td>
<td></td>
</tr>
</tbody>
</table>

Multiply the coefficient of CO₂ on product side by 2.

**Step of 3 of balancing:** Pick the third element to be balanced...

<table>
<thead>
<tr>
<th>Reactant side: C₂H₆ + O₂</th>
<th>Product side: 2CO₂ + 3H₂O</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 H atoms</td>
<td>12 H atoms</td>
<td>Hydrogen is balanced.</td>
</tr>
<tr>
<td>2 C atom</td>
<td>4 C atom</td>
<td>Carbon is balanced.</td>
</tr>
<tr>
<td>7 O atoms</td>
<td>14 O atoms</td>
<td>Oxygen is balanced.</td>
</tr>
</tbody>
</table>

To make the coefficient 9/2 a whole number multiply all by 2.

\[ 2 \text{C}_2\text{H}_6 + 7/2 \text{O}_2 \rightarrow 4 \text{CO}_2 + 6 \text{H}_2\text{O} \]

**Balanced chemical equation:** \[ 2 \text{C}_2\text{H}_6 + 7 \text{O}_2 \rightarrow 4 \text{CO}_2 + 6 \text{H}_2\text{O} \]

**Practice Problem** Indicate whether the following equations are balanced as written.

2 KNO₃ + 10 K ---> 6 K₂O + N₂ **Answer:** Atoms of all elements Balanced.

2 NH₃ + O₂ ---> N₂ + 3 H₂O **Answer:** Except O atoms, N and H atoms are balanced.

SF₄ + 3 H₂O ---> H₂SO₃ + 4 HF **Answer:** Atoms of all elements Balanced.

4 BF₃ + 3 H₂O ---> H₃BO₃ + 3 HBF₄ **Answer:** Atoms of all elements Balanced.

3 Cl₂ + 6 NaOH ---> 5 NaCl + NaClO₃ + 3 H₂O **Answer:** Atoms of all elements Balanced.

**Practice Problem** Balance the following equations.

TiCl₄ + H₂O ---> TiO₂ + HCl **Answer:** Stoichiometric coefficients: 1, 4, 1, 4

C₄H₁₀ + O₂ ---> CO₂ + H₂O **Answer:** Stoichiometric coefficients: 2, 13, 8, 10
WO₃ + H₂ ---> W + H₂O  \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 3, 1, 3}
Al₄C₃ + H₂O ---> Al(OH)₃ + CH₄ \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 12, 4, 3}
Al₂(SO₄)₃ + NaOH ---> Al(OH)₃ + Na₂SO₄ \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 6, 2, 3}
Ca₃P₂ + H₂O ---> Ca(OH)₂ + PH₃ \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 6, 3, 2}
Cl₂O₇ + H₂O ---> HClO₄ \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 1, 2}
MnO₂ + HCl ---> MnCl₂ + Cl₂ + H₂O \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 4, 1, 1, 2}
Fe + O₂ ---> Fe₃O₄ \hspace{1cm} \text{Answer: Stoichiometric coefficients: 3, 2, 1}
C₅H₁₂ + O₂ ---> CO₂ + H₂O \hspace{1cm} \text{Answer: Stoichiometric coefficients: 1, 8, 5, 6}

6.7 Chemical Equations and the Mole Concept

One of the most important information that we extract form a chemical equation is the mole conversion factors using stoichiometric coefficients. For example in the reaction:

\[ \text{O}_2(g) + 2 \text{H}_2(g) \rightarrow 2 \text{H}_2\text{O}(l) \]

\text{Stoichiometric and coefficients of } \text{O}_2, \text{H}_2 \text{ and } \text{H}_2\text{O} \text{ has 1, 1 and 2, as their stoichiometric coefficients, respectively. They are used to get the mole conversion factors for chemical calculations:}

\text{Mole conversion factors} \text{ are all simple cross combinations of stoichiometric coefficients written in moles: 1 \text{O}_2, 2 \text{H}_2 \text{ and } 2 \text{H}_2\text{O}.}

\[ \frac{1}{3} \text{O}_2 + 2 \text{H}_2 \rightarrow 2 \text{H}_2\text{O} \]

1) 1 mol \text{O}_2 = 2 mol \text{H}_2; \hspace{0.5cm} 2 mol \text{H}_2 = 2 mol \text{H}_2\text{O}
2) 1 mol \text{O}_2 = 2 mol \text{H}_2\text{O}

They are used in converting moles one chemical to another in the equation.

What are the mole conversion factors in the following equation?

\[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]

\[ \frac{2}{3} 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]

1) 4 mol \text{NH}_3 = 5 mol \text{O}_2
2) 4 mol \text{NH}_3 = 4 mol \text{NO} or 1 mole \text{NH}_3 = 1 mole \text{NO}
3) 4 mol \text{NH}_3 = 6 mol \text{H}_2\text{O} or 2 mol \text{NH}_3 = 3 mol \text{H}_2\text{O}
4) 5 mol \text{O}_2 = 4 mol \text{NO}
5) 5 mol \text{O}_2 = 6 mol \text{H}_2\text{O}

Converting moles of Reactants to Products

Once you have obtained the mole conversion factors any mole conversions could be carried out using factor label method. There is a important thing to remember in mole conversions: If there are more than one reactant. Never use the element in excess in mole conversions since it will be some left over at the end of the reaction.

Example: Calculate the following using the chemical equation given below:

\[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]
a) moles of NO(g) from 2 moles of NH3(g) and excess O2(g).
Get the mole conversion factor for NH3 and NO : 1 mole NH3 = 1 mole NO

\[
\frac{2 \text{ mol of NH}_3}{1} \times \frac{1 \text{ mol NO}}{1 \text{ mol of NH}_3} = 2 \text{ mol NO}
\]

b) moles of H2O(g) from 3 moles of O2(g) and excess NH3(g).
Get the mole conversion factor for O2 and H2O: 5 mole O2 = 6 mole H2O

\[
\frac{3 \text{ mol of O}_2}{1} \times \frac{6 \text{ mol H}_2\text{O}}{5 \text{ mol of O}_2} = 3.6 \text{ mol H}_2\text{O}
\]

**Practice problems:** Given the balanced chemical equation:

\[
2 \text{ C}_8\text{H}_{18} (l) + 25 \text{ O}_2 \rightarrow 16 \text{ CO}_2 + 18 \text{ H}_2\text{O}
\]

a) How many **moles** of H2O are produced when 2.81 moles of octane is burned?
(Answer: 25.3 mol of H2O)

b) How many **grams** of H2O are produced when 2.81 moles of octane is burned?
(Answer: 455.4 mol of H2O)

c) How many **moles** of CO2 are produced when 4.06 moles of oxygen is consumed?
(Answer: 2.60 mol of CO2)

d) How many **grams** of CO2 are produced when 4.06 moles of oxygen is consumed?
(Answer: 114.4 mol of CO2)

**6.8 Chemical Calculations Using Chemical Equations: Stiochiometry**

Stiochiometry is a general word that use for calculation of yield of products starting with certain amount of reactants in grams. The first step in a stoichiometric calculation is the conversion of grams of reactants moles of reactants by diving with formula mass. Then moles of reactants are converted moles products using mole conversion factor. Finally the grams of products are obtained by multiplying mole of products with formula mass.

**Stiochiometry problems involving grams of reactants and products**

**Example:** Calculate the following using the chemical equation given below:

\[
4 \text{ NH}_3(g) + 5 \text{ O}_2(g) \rightarrow 4 \text{ NO}(g) + 6 \text{ H}_2\text{O}(g)
\]

a) How many **grams of grams** of NO(g) is produced from 38.08 grams of NH3(g) and excess O2(g).
First convert 38.08 grams of NH3 to moles by diving grams by formula mass (NH3 = 17.04 g/mol), get the mole conversion factor for NH3 and NO: 1 mole NH3 = 1 mole NO, convert mole NH3 to mole NO and the convert mole NO to grams of NO by multiplying with by formula mass (NO = 30.01 g/mol) using factor label method:
b) **How many grams of H\textsubscript{2}O(g) is produced from 48.0 g of O\textsubscript{2}(g) and excess NH\textsubscript{3}(g).**

Get, the formula masses (H\textsubscript{2}O= 18.02 g/mol and O\textsubscript{2} = 32.00 g/mole) the mole conversion factor for moles O\textsubscript{2} to H\textsubscript{2}O: 5 mole O\textsubscript{2} = 6 mole H\textsubscript{2}O

\[
\frac{48.0 \text{ g O}_2}{1 \text{ mole O}_2} \times \frac{6 \text{ mole H}_2\text{O}}{5 \text{ mole O}_2} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mole H}_2\text{O}} = 32.44 \text{ g H}_2\text{O}
\]

**Practice problem:** Given the balanced chemical equation:

\[
\text{C}_7\text{H}_8 + 3 \text{ HNO}_3 \rightarrow \text{C}_7\text{H}_5\text{N}_3\text{O}_6 + 3 \text{ H}_2\text{O}
\]

What **mass of nitric acid**, in grams, is required to react with 454 g of C\textsubscript{7}H\textsubscript{8}?  
(Answer: 932.4 g of HNO\textsubscript{3})