CHEMICAL REACTIONS

15-16 year-olds

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Balancing Chemical Equations

The **law of conservation of mass** implies two **principles**:

1. The total number of atoms before and after a chemical reaction remains constant.
2. The number of atoms of each type is the same before and after the chemical reaction.

In a general **chemical equation**:

$$a\,\mathrm{A} + b\,\mathrm{B} \longrightarrow c\,\mathrm{C} + d\,\mathrm{D}$$

- A, B, C y D represent the **chemical symbols** of the atoms or the **molecular formula** of the compounds that react (left side) and the produced ones (right side).
- a, b, c y d represent the **stoichiometric coefficients**, that should be balanced following the **law of conservation of mass** (comparing from left to right, atom by atom, the number of each one that there is at each side of the arrow).

The **stoichiometric coefficients** indicate the number of atoms/molecules/**moles** which react/are produced of each element/compound.

Example

We want to balance the following chemical equation:

$$\mathrm{MnO_2} + \mathrm{HCl} \longrightarrow \mathrm{MnCl_2} + \mathrm{Cl_2} + \mathrm{H_2O}$$

Solution

We start with Mn: we see that we have 1 atom of Mn on the left side and also 1 atom on the right side. It is **balanced**.

Then we continue with O: we can see that there are 2 atoms of O on the left side and only one on the right side. Therefore, we must write a 2 before the water molecule:

$$\mathrm{MnO_2} + \mathrm{HCl} \longrightarrow \mathrm{MnCl_2} + \mathrm{Cl_2} + 2\,\mathrm{H_2O}$$

We continue with H: we have only one atom on the left side but $2 \times 2 = 4$ atoms on the right side. Therefore, we must write a 4 before the HCl:

$$\mathrm{MnO_2} + 4\,\mathrm{HCl} \longrightarrow \mathrm{MnCl_2} + \mathrm{Cl_2} + 2\,\mathrm{H_2O}$$

Finally, we go with Cl: since we have put 4 molecules of HCl there are 4 atoms of Cl on the left side. On the right side there are 2 atoms from the molecule of manganese chloride(II) and 2 more atoms from the chlorine molecule, 4 in total, so it is **balanced** and we do not have to add anything else.

The **balanced equation** will be:

$$\mathrm{MnO_2} + 4\,\mathrm{HCl} \longrightarrow \mathrm{MnCl_2} + \mathrm{Cl_2} + 2\,\mathrm{H_2O}$$

Mass-Mass Calculations

We perform these calculations when we have the mass (typically in g) of a chemical compound and we should calculate also the mass (usually in g) of another chemical compound.

We will follow these **three steps**:

1. **Change from g to mol** using the **molar mass**.
2. **Relate moles** of a compound with moles of another, using the **stoichiometric coefficients**.
3. **Change from mol to g** using the **molar mass**.

Example

Potassium chlorate, $\mathrm{KClO_3}$, breaks down into potassium chlorine, KCl, and oxygen. Calculate the mass of oxygen obtained in the decomposition of 86.8 g of potassium chlorate.

$M(\mathrm{K}) = 39.1\,\mathrm{g/mol}$; $M(\mathrm{Cl}) = 35.5\,\mathrm{g/mol}$; $M(\mathrm{O}) = 16\,\mathrm{g/mol}$.

Solution

We write the **chemical equation** for the decomposition:

$$\mathrm{KClO_3} \longrightarrow \mathrm{KCl} + \mathrm{O_2}$$

We **balance it**:

$$2\,\mathrm{KClO_3} \longrightarrow 2\,\mathrm{KCl} + 3\,\mathrm{O_2}$$

We calculate the **molar masses** of all the chemical compounds involved in the reaction:

$$\begin{aligned} M(\mathrm{KClO_3}) &= M(\mathrm{K}) + M(\mathrm{Cl}) + 3 \cdot M(\mathrm{O}) \\ &= 39.1\,\mathrm{g/mol} + 35.5\,\mathrm{g/mol} + 3 \cdot 16\,\mathrm{g/mol} = 122.6\,\mathrm{g/mol} \\ M(\mathrm{O_2}) &= 2 \cdot M(\mathrm{O}) = 2 \cdot 16\,\mathrm{g/mol} = 32\,\mathrm{g/mol} \end{aligned}$$

To relate the grams of potassium chlorate with the grams of oxygen we use the three steps of the **mass-mass calculations**:

$$86.8\,\cancel{\mathrm{g_{KClO_3}}} \cdot \frac{1\,\cancel{\mathrm{mol_{KClO_3}}}}{122.6\,\cancel{\mathrm{g_{KClO_3}}}} \cdot \frac{3\,\cancel{\mathrm{mol_{O_2}}}}{2\,\cancel{\mathrm{mol_{KClO_3}}}} \cdot \frac{32\,\mathrm{g_{O_2}}}{1\,\cancel{\mathrm{mol_{O_2}}}} = 34.0\,\mathrm{g_{O_2}}$$

Reactants in Solution

When the REACTANTS are solved in a SOLUTION, we have to relate the number of moles, n, with the volume, V, through the molar concentration or MOLARITY:

$$c = \frac{n}{V} \rightarrow n = cV \quad (V \text{ in L})$$

Example

Hydrochloric acid reacts with calcium hydroxide to produce calcium chloride and water. Calculate the volume of hydrochloric acid 0.25 M needed to react with 50 mL of calcium hydroxide 0.5 M.

$$2\,\mathrm{HCl(ac)} + \mathrm{Ca(OH)_2(ac)} \longrightarrow \mathrm{CaCl_2(ac)} + 2\,\mathrm{H_2O(l)}$$

Solution

$$50\,\cancel{\mathrm{mL_{Ca(OH)_2}}} \cdot \frac{1\,\cancel{\mathrm{L_{Ca(OH)_2}}}}{1000\,\cancel{\mathrm{mL_{Ca(OH)_2}}}} \cdot \frac{0.5\,\cancel{\mathrm{mol_{Ca(OH)_2}}}}{1\,\cancel{\mathrm{L_{Ca(OH)_2}}}} \cdot \frac{2\,\cancel{\mathrm{mol_{HCl}}}}{1\,\cancel{\mathrm{mol_{Ca(OH)_2}}}} \cdot \frac{1\,\mathrm{L_{HCl}}}{0.25\,\cancel{\mathrm{mol_{HCl}}}} = 0.2\,\mathrm{L_{HCl}}$$

Mass-Volume Calculations

If any of the compounds in the reaction is a gas, we need to use the **ideal gas law**:

$$pV = nRT$$

- p is the **pressure** of the gass measured in atm.
- V is the **volume** of the gas measured in L.
- n is the **number of moles** that we have of the gas, which can be related with the mass through the **molar mass**.
- $R = 0.082\,\frac{\mathrm{atm\,L}}{\mathrm{mol\,K}}$ is the **ideal gas constant**.
- T is the **temperature** of the gas, measured in K: $T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273$.

Example

Calculate the volume of hydrogen, measured at 25 °C and 0.98 atm, produced when 41.4 g of sodium react with water:

$$2\,\mathrm{Na(s)} + 2\,\mathrm{H_2O(l)} \longrightarrow 2\,\mathrm{NaOH(aq)} + \mathrm{H_2(g)}$$

$M(\mathrm{Na}) = 23\,\mathrm{g/mol}$; $M(\mathrm{H}) = 1\,\mathrm{g/mol}$; $M(\mathrm{O}) = 16\,\mathrm{g/mol}$.

Solution

The equation is already **written** and **balanced**. Pay attention to the characters between brackets, which indicate the **state of aggregation** of each chemical compound:

- (s) → **solid**
- (l) → **liquid**
- (g) → **gas**
- (aq) → **aqueous solution**

First we calculate the **molar masses** of the compounds involved:

$$\begin{aligned} M(\mathrm{Na}) &= 23\,\mathrm{g/mol} \\ M(\mathrm{H_2}) &= 2 \cdot M(\mathrm{H}) = 2 \cdot 1\,\mathrm{g/mol} = 2\,\mathrm{g/mol} \end{aligned}$$

From the grams of Na we calculate the moles of $\mathrm{H_2}$ that will be obtained, using the first two steps of the **mass-mass calculations**:

$$41.4\,\cancel{\mathrm{g_{Na}}} \cdot \frac{1\,\cancel{\mathrm{mol_{Na}}}}{23\,\cancel{\mathrm{g_{Na}}}} \cdot \frac{1\,\mathrm{mol_{H_2}}}{2\,\cancel{\mathrm{mol_{Na}}}} = 0.9\,\mathrm{mol_{H_2}}$$

To relate the amount of hydrogen obtained (measured in mol) with the volume (measured in L), we use the **ideal gas law**:

$$pV = nRT$$

The temperature T should be in K:

$$\begin{aligned} T(\mathrm{K}) &= T(^\circ\mathrm{C}) + 273 \\ &= 25\,^\circ\mathrm{C} + 273 = 298\,\mathrm{K} \end{aligned}$$

We solve for the volume V:

$$V = \frac{nRT}{p} = \frac{0.9\,\cancel{\mathrm{mol}} \cdot 0.082\,\frac{\cancel{\mathrm{atm}}\,\mathrm{L}}{\cancel{\mathrm{mol}}\,\cancel{\mathrm{K}}} \cdot 298\,\cancel{\mathrm{K}}}{0.98\,\cancel{\mathrm{atm}}} = 22.4\,\mathrm{L_{H_2}}$$