

CHEMICAL REACTIONS

15-16 year-olds

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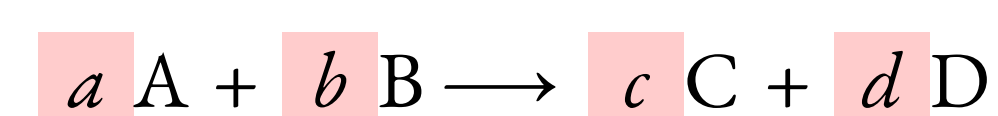


Balancing Chemical Equations

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, 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 (or volume if the intervening substances are gases under the same conditions of pressure and temperature).

Example

We want to balance the following chemical equation:



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:



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:



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:



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**.

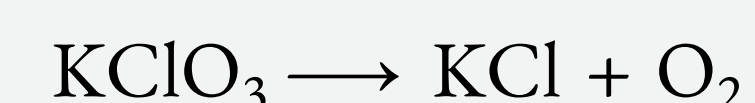
Example

Potassium chlorate, KClO_3 , breaks down into potassium chloride, KCl , and oxygen. Calculate the mass of oxygen obtained in the decomposition of 86.8 g of potassium chlorate.

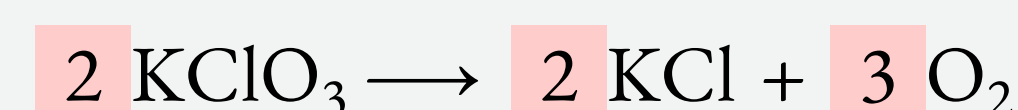
$$M(\text{K}) = 39.1 \text{ g/mol}; M(\text{Cl}) = 35.5 \text{ g/mol}; M(\text{O}) = 16 \text{ g/mol}.$$

Solution

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



We **balance it**:



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

$$\begin{aligned} M(\text{KClO}_3) &= M(\text{K}) + M(\text{Cl}) + 3 \cdot M(\text{O}) \\ &= 39.1 \text{ g/mol} + 35.5 \text{ g/mol} + 3 \cdot 16 \text{ g/mol} = 122.6 \text{ g/mol} \\ M(\text{O}_2) &= 2 \cdot M(\text{O}) = 2 \cdot 16 \text{ g/mol} = 32 \text{ g/mol} \end{aligned}$$

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

$$86.8 \text{ g}_{\text{KClO}_3} \cdot \frac{1 \text{ mol}_{\text{KClO}_3}}{122.6 \text{ g}_{\text{KClO}_3}} \cdot \frac{3 \text{ mol}_{\text{O}_2}}{2 \text{ mol}_{\text{KClO}_3}} \cdot \frac{32 \text{ g}_{\text{O}_2}}{1 \text{ mol}_{\text{O}_2}} = 34.0 \text{ g}_{\text{O}_2}$$

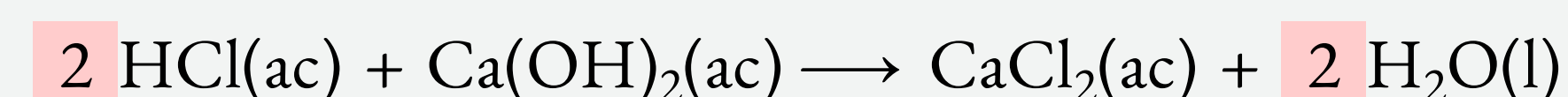
Reactants in Solution

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.



Solution

$$50 \text{ mL}_{\text{Ca}(\text{OH})_2} \cdot \frac{1 \text{ L}_{\text{Ca}(\text{OH})_2}}{1000 \text{ mL}_{\text{Ca}(\text{OH})_2}} \cdot \frac{0.5 \text{ mol}_{\text{Ca}(\text{OH})_2}}{1 \text{ L}_{\text{Ca}(\text{OH})_2}} \cdot \frac{2 \text{ mol}_{\text{HCl}}}{1 \text{ mol}_{\text{Ca}(\text{OH})_2}} \cdot \frac{1 \text{ L}_{\text{HCl}}}{0.25 \text{ mol}_{\text{HCl}}} = 0.2 \text{ L}_{\text{HCl}}$$

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 gas 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**.
- $R = 0.082 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}$ is the **ideal gas constant**.
- T is the **temperature** of the gas, measured in K: $T(\text{K}) = T(^{\circ}\text{C}) + 273$.

Example

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



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

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:

$$\begin{aligned} M(\text{Na}) &= 23 \text{ g/mol} \\ M(\text{H}_2) &= 2 \cdot M(\text{H}) = 2 \cdot 1 \text{ g/mol} = 2 \text{ g/mol} \end{aligned}$$

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

$$41.4 \text{ g}_{\text{Na}} \cdot \frac{1 \text{ mol}_{\text{Na}}}{23 \text{ g}_{\text{Na}}} \cdot \frac{1 \text{ mol}_{\text{H}_2}}{2 \text{ mol}_{\text{Na}}} = 0.9 \text{ mol}_{\text{H}_2}$$

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:

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

We solve for the volume V :

$$V = \frac{nRT}{p} = \frac{0.9 \text{ mol} \cdot 0.082 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K}}{0.98 \text{ atm}} = 22.4 \text{ L}_{\text{H}_2}$$