

Additional examples for exercise 5: Reaction equations and stoichiometry in reaction equations

Example 1:

Write down the chemical formulas for the following ionic compounds (salts):

- a) Magnesium sulfate

Solution: MgSO_4

- b) Calcium chloride

Solution: CaCl_2

- a) Potassium fluoride

Solution: KF

Example 2:

Balance the following reaction equations:

- a) $\text{Al}_{(s)} + \text{Cl}_{2(g)} \rightarrow \text{AlCl}_{3(s)}$

Solution: $2 \text{Al}_{(s)} + 3 \text{Cl}_{2(g)} \rightarrow 2 \text{AlCl}_{3(s)}$

- b) $\text{Ca(OH)}_{2(aq)} + \text{HBr}_{(aq)} \rightarrow \text{CaBr}_{2(aq)} + \text{H}_2\text{O}_{(l)}$

Solution: $\text{Ca(OH)}_{2(aq)} + 2 \text{HBr}_{(aq)} \rightarrow \text{CaBr}_{2(aq)} + 2 \text{H}_2\text{O}_{(l)}$

- a) $\text{N}_2\text{O}_{5(s)} + \text{H}_2\text{O}_{(l)} \rightarrow \text{HNO}_{3(l)}$

Solution: $\text{N}_2\text{O}_{5(s)} + \text{H}_2\text{O}_{(l)} \rightarrow 2 \text{HNO}_{3(l)}$

- b) $\text{HCl}_{(g)} + \text{CaO}_{(s)} \rightarrow \text{CaCl}_{2(s)} + \text{H}_2\text{O}_{(g)}$

Solution: $2 \text{HCl}_{(g)} + \text{CaO}_{(s)} \rightarrow \text{CaCl}_{2(s)} + \text{H}_2\text{O}_{(g)}$

Example 3:

Write a complete chemical equation for the following reactions described in words:

- a) Phosphine $\text{PH}_3(g)$ burns in air to form gaseous water and solid diphosphorus pentoxide.

Solution: $2 \text{PH}_3(g) + 4 \text{O}_2(g) \rightarrow \text{P}_2\text{O}_5(s) + \text{H}_2\text{O}(g)$

- b) When ammonia gas NH_3 is passed over liquid, hot sodium (metallic), hydrogen is released and a solid of sodium amide NaNH_2 is formed.

Solution: $2 \text{NH}_3(g) + 2 \text{Na}(s) \rightarrow \text{H}_2(g) + 2 \text{NaNH}_2(s)$

- c) Liquid phosphorus trichloride is added to water and reacts violently to form dissolved hydrochloric acid HCl and phosphoric acid H_3PO_4 .

Solution: $\text{PCl}_3(l) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{PO}_3(aq) + 3 \text{HCl}(aq)$

- d) Solid potassium nitrate is heated and decomposes to solid potassium nitrite with the formation of oxygen gas.

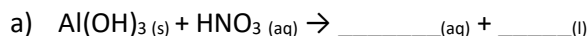
Solution: $2 \text{KNO}_3(s) \rightarrow 2 \text{KNO}_2(s) + \text{O}_2(g)$

- e) Hydrogen sulfide gas H_2S is passed over solid, hot iron(III) hydroxide, forming solid iron(III) sulfide and gaseous water.

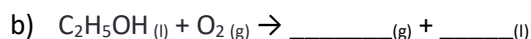
Solution: $3 \text{H}_2\text{S}(g) + 2 \text{Fe(OH)}_3(s) \rightarrow \text{Fe}_2\text{S}_3(s) + 6 \text{H}_2\text{O}(g)$

Example 4:

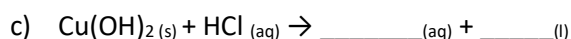
Complete the following reaction equation (add stoichiometric factors!) and describe in words what happens during the reaction:



Solid aluminum hydroxide (alumina) is dissolved in nitric acid. This produces water and (aq) aluminum nitrate dissolved in it.



Ethanol (organic compound) oxidizes (combustion reaction) to form gaseous carbon dioxide and water.



Solid copper hydroxide is dissolved in hydrochloric acid. This produces water and dissolved copper chloride.

Example 5:

Write a complete chemical equation for the following reactions described in words:

- a) Boron sulfide $\text{B}_2\text{S}_3 (\text{s})$ reacts violently with water to form dissolved boric acid H_3BO_3 and hydrogen sulfide gas H_2S (hydrolysis = splitting of a chemical compound through reaction with water).



- b) Metallic copper reacts with hot, concentrated sulfuric acid to form an aqueous solution of copper(II) sulfate and water, as well as gaseous sulfur dioxide.

**Example 6:**

Write a complete chemical equation for the following reactions described in words:

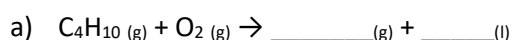
- a) Gaseous cyanic acid HOCN is very unstable and is hydrolyzed in water to form ammonia and gaseous carbon dioxide.



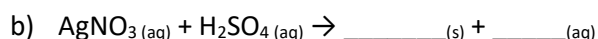
- b) If solid mercury(II) nitrate is heated, it decomposes into solid mercury(II) oxide and into gaseous nitrogen dioxide and oxygen.

**Example 7:**

Complete the following reaction equation (add stoichiometric factors!) and describe in words what happens during the reaction:



Butane oxidizes (combustion reaction) to gaseous carbon dioxide and water.

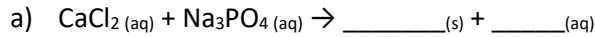




Precipitation reaction: 2 solutions, one silver nitrate solution and one sulfuric acid solution, are mixed together. Silver sulfate precipitates and nitric acid forms.

Example 8:

Complete the following reaction equation (add stoichiometric factors!) and describe the processes during the reaction in words:



Precipitation reaction: 2 solutions, one calcium chloride solution and one sodium phosphate solution, are mixed together. Calcium phosphate precipitates out as a solid. The NaCl (common salt) ions (Na^+ , Cl^-) remain dissolved.

Example 9:

5.38 g Li_3N is reacted with an arbitrary amount of water to form ammonia.

- a) Set up the reaction equation



- b) What mass of ammonia is formed?

Molar mass:

$M_{\text{Li}_3\text{N}} = 3 \cdot 6.94 + 14.007 = 34.827 \text{ g/mol}$

$M_{\text{NH}_3} = 14.007 + 3 \cdot 1.008 = 17.031 \text{ g/mol}$

Amount of substance:

$m_{\text{Li}_3\text{N}} = 5.38 \text{ g} \rightarrow$ that means $n_{\text{Li}_3\text{N}} = m_{\text{Li}_3\text{N}}/M_{\text{Li}_3\text{N}} = 0.154478 \text{ mol Li}_3\text{N}$

According to the reaction equation, 1 mol Li_3N reacts to form 1 mol NH_3 . Consequently, 0.154478 mol Li_3N reacts to form 0.154478 mol NH_3 .

Mass of ammonia after complete reaction:

It forms 0.154478 mol NH_3 . Therefore, $0.154478 \text{ mol} \cdot 17.031 \text{ g/mol} = 2.63 \text{ g NH}_3$.

Example 10:

In the synthesis of ammonia, only 6.8 t of ammonia are produced from 45 t of nitrogen. Create the reaction equation and determine the yield.



Molar mass:

$M_{\text{N}_2} = 2 \cdot 14.007 = 28.014 \text{ g/mol}$

$M_{\text{NH}_3} = 14.007 + 3 \cdot 1.008 = 17.031 \text{ g/mol}$

Amount of substance:

$m_{\text{N}_2} = 45 \text{ t} = 45\,000\,000 \text{ g} \rightarrow$ therefore $n_{\text{N}_2} = m_{\text{N}_2}/M_{\text{N}_2} = 1\,606\,339.687 \text{ mol N}_2$

$m_{\text{NH}_3} = 6.8 \text{ t} = 6\,800\,000 \text{ g} \rightarrow \text{therefore } n_{\text{NH}_3} = m_{\text{NH}_3}/M_{\text{NH}_3} = 399\,271.916 \text{ mol NH}_3$

in theory, $1\,606\,339,687 \text{ mol N}_2$ should produce $3\,212\,679,374 \text{ mol NH}_3$. That is, $3\,212\,679.374 \text{ mol} * 17.031 \text{ g/mol} = 55 \text{ t NH}_3$. The yield is $m_{\text{prakt.}}/m_{\text{theor.}} = 6.8/55 = 12.36 \%$.

Example 11:

When burning 22.00 g of propane C_3H_8 , 15.0 g of water was collected. What is the percentage of propane that has burned?

Reaction equation: $\text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4 \text{H}_2\text{O}$

Molar mass:

$M_{\text{C}_3\text{H}_8} = 3 * 12.011 + 8 * 1.008 = 44.097 \text{ g/mol}$

$M_{\text{H}_2\text{O}} = 2 * 1.008 + 15.999 = 18.015 \text{ g/mol}$

Amount of substance:

$m_{\text{H}_2\text{O}} = 15.0 \text{ g} \rightarrow \text{that is } n_{\text{H}_2\text{O}} = m_{\text{H}_2\text{O}}/M_{\text{H}_2\text{O}} = 0.832639 \text{ mol H}_2\text{O}$

According to the reaction equation, 1 mol C_3H_8 reacts to 4 mol H_2O . Consequently, $0.20816 \text{ mol C}_3\text{H}_8$ ($0.20816 \text{ mol} * 44.097 \text{ g/mol} = 9.17923 \text{ g}$) must theoretically be burned for $0.832639 \text{ mol H}_2\text{O}$.

Yield:

$m_{\text{prakt., C}_3\text{H}_8}/m_{\text{theor., C}_3\text{H}_8} = 9.17923/22.00 = 41.7 \%$

Example 12:

A rock consists of 92% magnesium carbonate. Heating produces magnesium oxide and carbon dioxide. Write down the reaction equation. How many tons of magnesium oxide can you get by heating 5 tons of the rock?

Reaction equation: $\text{MgCO}_3(\text{s}) \rightarrow \text{MgO}(\text{s}) + \text{CO}_2(\text{g})$

Molar mass:

$M_{\text{MgCO}_3} = 24.305 + 12.011 + 3 * 15.999 = 84.313 \text{ g/mol}$

$M_{\text{MgO}} = 24.305 + 15.999 = 40.304 \text{ g/mol}$

5 t of rock contains 92% magnesium carbonate, so 5 t of rock contains $5 \text{ t} * 0.92 = 4.6 \text{ t}$ of MgCO_3 .

Amount of substance:

$m_{\text{MgCO}_3} = 4.6 \text{ t} = 4\,600\,000 \text{ g} \rightarrow \text{that is } n_{\text{MgCO}_3} = m_{\text{MgCO}_3}/M_{\text{MgCO}_3} = 54558.61 \text{ mol MgCO}_3$

According to the reaction equation, 1 mol MgCO_3 reacts to form 1 mol MgO . Consequently, 54558.61 moles of MgCO_3 react to form 54558.61 moles of MgO .

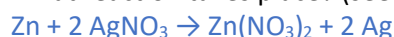
Mass of magnesium oxide after complete reaction:

It forms 54558.61 mol MgO . Therefore, $54558.61 \text{ mol} * 40.304 \text{ g/mol} = 2.199 \text{ t MgO}$.

Example 13:

A strip of zinc metal weighing 2.00 grams is placed in an aqueous solution of 2.50 grams of silver nitrate.

a) What reaction takes place? (see exercise)



- b) Which reactant is limiting? (see exercise)

Molar mass:

$$M_{\text{Zn}} = 65.380 \text{ g/mol}$$

$$M_{\text{AgNO}_3} = 107.87 + 14.007 + 3 * 15.999 = 169.874 \text{ g/mol}$$

Amount of substance:

$$M_{\text{Zn}} = 2.00 \text{ g} \rightarrow \text{that is } n_{\text{Zn}} = m_{\text{Zn}}/M_{\text{Zn}} = 0.03059 \text{ mol Zn}$$

$$M_{\text{AgNO}_3} = 2.00 \text{ g} \rightarrow \text{that is } n_{\text{AgNO}_3} = m_{\text{AgNO}_3}/M_{\text{AgNO}_3} = 0.014717 \text{ mol AgNO}_3$$



- c) How many g of Ag are formed?

Molar mass:

$$M_{\text{Ag}} = 107.87 \text{ g/mol}$$

$$0.014717 \text{ mol Ag are formed. That is } 0.014717 \text{ mol} * 107.87 \text{ g/mol} = 1.59 \text{ g Ag.}$$

- d) How many g of $\text{Zn(NO}_3)_2$ are formed?

Molar mass:

$$M_{\text{Zn(NO}_3)_2} = 65.380 + 2 * (14.007 + 3 * 15.999) = 189.388 \text{ g/mol}$$

$$0.0073585 \text{ mol Zn(NO}_3)_2 \text{ are formed. That is } 0.0073585 \text{ mol} * 189.388 \text{ g/mol} = 1.39 \text{ g Zn(NO}_3)_2.$$

- e) What is the mass of excess reactant left at the end of the reaction?

$$0.0232315 \text{ mol of Zn remain. That is } 0.0232315 \text{ mol} * 65.380 \text{ g/mol} = 1.52 \text{ g Zn.}$$

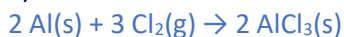
- f) To what percentage has the reaction gone to completion?

$$0.48 \text{ g of the } 2.00 \text{ g of Zn present react. The reaction has run to } (0.48/2)*100 = 24\% \text{ completion.}$$

Example 14:

Consider the reaction of aluminum with elemental chlorine to form aluminum chloride. A mixture of 4.00 mol Al and 10.0 mol Cl_2 is reacted.

- a) a) Write down the reaction equation. (see exercise)



- b) Which reactant is limiting? (see exercise)



- c) How many mol of AlCl_3 are formed?

According to the reaction equation: 2 mol AlCl_3 are formed from 2 mol Al. Consequently, 4 mol AlCl_3 are formed from 4 mol Al.

- d) How many moles of excess reactant are there at the end of the reaction?

For the reaction (see b) 6 mol Cl_2 are consumed. This leaves 4 moles of Cl_2 .

- e) How many g of AlCl_3 are formed?

Molar mass:

$$M_{\text{AlCl}_3} = 26.982 + 3 * 35.45 = 133.332 \text{ g/mol}$$

It forms 4 mol AlCl_3 . Therefore $4 \text{ mol} * 133.332 \text{ g/mol} = 533 \text{ g AlCl}_3$.