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) $Al_{(s)} + Cl_{2\,(g)} \rightarrow AlCl_{3\,(s)}$

Solution: $2\ Al_{(s)} + 3\ Cl_{2\,(g)} \rightarrow 2\ AlCl_{3\,(s)}$

b) $Ca(OH)_{2\,(aq)} + HBr_{(aq)} \rightarrow CaBr_{2\,(aq)} + H_2O_{(l)}$

Solution: $Ca(OH)_{2\,(aq)} + 2\ HBr_{(aq)} \rightarrow CaBr_{2\,(aq)} + 2\ H_2O_{(l)}$

a) $N_2O_{5\,(s)} + H_2O_{(l)} \rightarrow HNO_{3\,(l)}$

Solution: $N_2O_{5\,(s)} + H_2O_{(l)} \rightarrow 2\ HNO_{3\,(l)}$

b) $HCl_{(g)} + CaO_{(s)} \rightarrow CaCl_{2\,(s)} + H_2O_{(g)}$

Solution: $2\ HCl_{(g)} + CaO_{(s)} \rightarrow CaCl_{2\,(s)} + H_2O_{(g)}$

Example 3:

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

a) Phosphine $PH_{3\,(g)}$ burns in air to form gaseous water and solid diphosphorus pentoxide.

Solution: $2\ PH_{3\,(g)} + 4\ O_{2\,(g)} \rightarrow P_2O_{5\,(s)} + H_2O_{(g)}$

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: $2\ NH_{3\,(g)} + 2\ Na_{(s)} \rightarrow H_{2\,(g)} + 2\ NaNH_{2\,(s)}$

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

Solution: $PCl_{3\,(l)} + H_2O_{(l)} \rightarrow H_3PO_{3\,(aq)} + 3\ HCl_{(aq)}$

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

Solution: $2\ KNO_{3\,(s)} \rightarrow 2\ KNO_{2\,(s)} + O_{2\,(g)}$

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

Solution: $3\ H_2S_{(g)} + 2\ Fe(OH)_{3\,(s)} \rightarrow Fe_2S_{3\,(s)} + 6\ H_2O_{(g)}$

Example 4:
Complete the following reaction equation (add stoichiometric factors!) and describe in words what happens during the reaction:

a) $Al(OH)_{3\,(s)} + HNO_{3\,(aq)} \rightarrow$ _____$_{(aq)}$ + _____$_{(l)}$

Solution: $Al(OH)_{3\,(s)} + 3\ HNO_{3\,(aq)} \rightarrow Al(NO_3)_{3\,(aq)} + 3\ H_2O_{\,(l)}$
Solid aluminum hydroxide (alumina) is dissolved in nitric acid. This produces water and (aq) aluminum nitrate dissolved in it.

b) $C_2H_5OH_{\,(l)} + O_{2\,(g)} \rightarrow$ _____$_{(g)}$ + _____$_{(l)}$

Solution: $C_2H_5OH_{(l)} + 3\ O_{2\,(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(l)}$
Ethanol (organic compound) oxidizes (combustion reaction) to form gaseous carbon dioxide and water.

c) $Cu(OH)_{2\,(s)} + HCl_{\,(aq)} \rightarrow$ _____$_{(aq)}$ + _____$_{(l)}$

Solution: $Cu(OH)_{2\,(s)} + 2\ HCl_{\,(aq)} \rightarrow CuCl_{2\,(aq)} + 2\ H_2O_{\,(l)}$
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 $B_2S_{3\,(s)}$ 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).

Solution: $B_2S_{3\,(s)} + 6\ H_2O_{\,(l)} \rightarrow 2\ H_3BO_{3\,(aq)} + 3\ H_2S_{\,(g)}$

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.

Solution: $Cu_{\,(s)} + 2\ H_2SO_{4\,(l)} \rightarrow CuSO_{4\,(s)} + 2\ H_2O_{\,(l)} + SO_{2\,(g)}$

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.

Solution: $HOCN_{\,(g)} + H_2O_{\,(l)} \rightarrow NH_{3\,(g)} + CO_{2\,(g)}$

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

Solution: $2\ Hg(NO_3)_{2\,(s)} \rightarrow 2\ HgO_{\,(s)} + 4\ NO_{2\,(g)} + O_{2\,(g)}$

Example 7:
Complete the following reaction equation (add stoichiometric factors!) and describe in words what happens during the reaction:

a) $C_4H_{10\,(g)} + O_{2\,(g)} \rightarrow$ _____$_{(g)}$ + _____$_{(l)}$

Solution: $2\ C_4H_{10\,(g)} + 13\ O_{2\,(g)} \rightarrow 8\ CO_{2(g)} + 3\ H_2O_{(l)}$
Butane oxidizes (combustion reaction) to gaseous carbon dioxide and water.

b) $AgNO_{3\,(aq)} + H_2SO_{4\,(aq)} \rightarrow$ _____$_{(s)}$ + _____$_{(aq)}$

Solution: $2\ AgNO_{3\ (aq)} + H_2SO_{4\ (aq)} \rightarrow Ag_2SO_{4\ (s)} + 2\ HNO_{3\ (aq)}$
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:

a) $CaCl_{2\ (aq)} + Na_3PO_{4\ (aq)} \rightarrow$ _____$_{(s)}$ + _____$_{(aq)}$

Solution: $3\ CaCl_{2\ (aq)} + 2\ Na_3PO_{4\ (aq)} \rightarrow Ca_3(PO_4)_{2\ (s)} + 6\ NaCl_{\ (aq)}$
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
$Li_3N(s) + 3\ H_2O(l) \rightarrow NH_3(g) + 3\ LiOH(s)$

b) What mass of ammonia is formed?
Molar mass:
$M_{Li3N} = 3*6.94 + 14.007 = 34.827$ g/mol
$M_{NH3} = 14.007 + 3*1.008 = 17.031$ g/mol

Amount of substance:
$m_{Li3N} = 5.38$ g -> that means $n_{Li3N} = m_{Li3N}/M_{Li3N} = 0.154478$ mol Li_3N
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 mol * 17.031 g/mol = 2.63 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.

Reaction equation: $N_2 + 3\ H_2 \rightleftarrows 2\ NH_3$

Molar mass:
$M_{N2} = 2 * 14.007 = 28.014$ g/mol
$M_{NH3} = 14.007 + 3 * 1.008 = 17.031$ g/mol

Amount of substance:
$m_{N2} = 45$ t = 45 000 000 g -> therefore $n_{N2} = m_{N2}/M_{N2} = 1\ 606\ 339.687$ mol N_2

m_{NH3} = 6.8 t = 6 800 000 g -> therefore $n_{NH3} = m_{NH3}/M_{NH3}$ = 399 271.916 mol NH_3

in theory, 1 606 339,687 mol N_2 should produce 3 212 679,374 mol NH_3. That is, 3 212 679.374 mol * 17.031 g/mol = 55 t NH_3. The yield is $m_{prakt.}/m_{theor.}$ = 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: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4\ H_2O$

Molar mass:
M_{C3H8} = 3 * 12.011 + 8 * 1.008 = 44.097 g/mol
M_{H2O} = 2 * 1.008 + 15.999 = 18.015 g/mol

Amount of substance:
m_{H2O} = 15.0 g -> that is $n_{H2O} = m_{H2O}/M_{H2O}$ = 0.832639 mol H_2O
According to the reaction equation, 1 mol C_3H_8 reacts to 4 mol H_2O. Consequently, 0.20816 mol C_3H_8 (0.20816 mol * 44.097 g/mol = 9.17923 g) must theoretically be burned for 0.832639 mol H_2O.

Yield:
$m_{prakt., C3H8}/\ m_{theor., C3H8}$ = 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: $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

Molar mass:
$MgCO_3$ = 24.305 + 12.011 + 3 * 15.999 = 84.313 g/mol
MgO = 24.305 + 15.999 = 40.304 g/mol

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

Amount of substance:
m_{MgCO3} = 4.6 t = 4 600 000g -> that is $n_{MgCO3} = m_{MgCO3}/M_{MgCO3}$ = 54558.61 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 mol * 40.304 g/mol = 2.199 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)
   $Zn + 2\ AgNO_3 \rightarrow Zn(NO_3)_2 + 2\ Ag$

b) Which reactant is limiting? (see exercise)
Molar mass:
M_{Zn} = 65.380 g/mol
M_{AgNO3} = 107.87 + 14.007 + 3 * 15.999 = 169.874 g/mol

Amount of substance:
M_{Zn} = 2.00 g -> that is $n_{Zn} = m_{Zn}/M_{Zn}$ = 0.03059 mol Zn
M_{AgNO3} = 2.00 g -> that is $n_{AgNO3} = m_{AgNO3}/M_{AgNO3}$ = 0.014717 mol $AgNO_3$

0.0073585 Zn + 0.014717 $AgNO_3$ → 0.0073585 $Zn(NO_3)_2$ + 0.014717 Ag; $AgNO_3$ is limiting

c) How many g of Ag are formed?
Molar mass:
M_{Ag} = 107.87 g/mol

0.014717 mol Ag are formed. That is 0.014717 mol * 107.87 g/mol = 1.59 g Ag.

d) How many g of $Zn(NO_3)_2$ are formed?
Molar mass:
$M_{Zn(NO3)2}$ = 65.380 + 2 * (14.007 + 3 * 15.999) = 189.388 g/mol

0.0073585 mol $Zn(NO_3)_2$ are formed. That is 0.0073585 mol * 189.388 g/mol = 1.39 g $Zn(NO_3)_2$.

e) What is the mass of excess reactant left at the end of the reaction?
0.0232315 mol of Zn remain. That is 0.0232315 mol * 65.380 g/mol = 1.52 g Zn.

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

0.48 g of the 2.00 g of Zn present react. The reaction has run to (0.48/2)*100 = 24% 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)
2 Al(s) + 3 Cl_2(g) → 2 $AlCl_3$(s)

b) Which reactant is limiting? (see exercise)
4 Al(s) + 6 Cl_2(g) → 4 $AlCl_3$(s); 4 mol Al react with 6 mol Cl_2 -> Al is limiting.

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:

$M_{AlCl3} = 26.982 + 3 * 35.45 = 133.332$ g/mol

It forms 4 mol $AlCl_3$. Therefore 4 mol * 133.332 g/mol = 533 g $AlCl_3$.