Problems
Задачи

NINE HYPOTHETICAL PROBLEMS FOR LINKAGE BETWEEN QUALITATIVE ANALYSIS AND STOICHIOMETRIC CALCULATIONS

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Abstract. On the science or the chemistry education, it is one from the most important problems for both the science teachers and the students to design the linkage between ones information and other information as well. The aim of this study is hypothetically to model the linkage between the qualitative analysis and the quantitative analysis with the chemical calculations. For this aim, it is preferred the precipitation reactions of first group cations (Ag^{1+}, Pb^{2+}, Hg_2^{2+}) with HCl solution that is the group reagent in the qualitative analysis of inorganic samples in this study. On these precipitation reactions, it is offered the three sub model for teaching how to calculate the quantity of precipitate if the quantities of one or two reactants are given for the quantitative analysis. These sub models are consecutively called First Model, Second Model and Third Model. *First Model:* The aim of First Model is to teach how to calculate the mass of precipitate when the molarity and the volume of the solution of only one reactant is given in the problems. *Second Model:* The aim of Second Model is to teach how to calculate the mass of precipitate if two reactants react completely when the molarities and the volumes of the solution of them are given in the problems. *Third Model:* The aim of Third Model is to teach how to calculate the mass of precipitate if one of two reactants reacts completely and other remains unreacted when the molarities and the volumes of their solutions are given in the problems. The solutions of problems have been done by two different methods that are known as by the using formula and by the conversion factor. It can be said that the models are hypothetically suitable to investigate the relations between the qualitative analysis and the quantitative analysis with the chemical calculation in this context the reactions of first group cations with HCl that is the group reagent of them. The precipitation reactions are directly the linkage with gravimetric analysis and Mohr, Fajans and Volhard methods in this context of volumetric analysis as well.

Keywords: analytical chemistry education, qualitative analysis, quantitative analysis, quantitative precipitation, stoichiometry, chemical calculation, limiting reagent

Introduction

Precipitation reactions have been used in general chemistry laboratories (Ricci & Ditzler, 1991), to teach solubility rules (Blake, 2003), the stoichiometry of reactions, and the concepts of the limiting reactant, percent yield, and equilibrium (De Meo, 2002). It was modeled by three hypothetical problems for the teaching of quantitative precipitation in analytical chemistry teaching how the stoichiometric calculations can be done to determine hypothetically the appropriate conditions for the quantitative precipitation (Ergül, 2015). Because the hypothetical problems for qualitative and quantitative analysis are not present in literature in this context analytical chemistry education, I offer nine hypothetical problems.

In the analytical chemistry education, acid-base reactions, redox reactions, complexation reactions and precipitation reactions are used for the qualitative and the quantitative analysis in analytical chemistry laboratories. The precipitation reactions are used for classic qualitative and quantative analyses of both cations and anions. In addition, these reactions are directly used for quantitative analysis on gravimetric analysis and on volumetric analyses such as Mohr, Fajans and Volhard methods.

On the qualitative analysis, inorganic compounds are divided into two groups as cations and the anions. The cations are also subdivided into five groups in the qualitative analysis of inorganic compounds. Each cation groups have a precipitating reagent. The all of the cations in the group are precipitated as more slightly soluble salt by the solution of this reagent.

First group cations are Ag^{1+}, Pb^{2+} and Hg_2^{2+}. The group reagent for first group cations is 0.1 M HCl or 0.1 M NaCl solution. The first group cations precipitate as chloride salts such as AgCl, $PbCl_2$ and Hg_2Cl_2 when the solution of these cations is mixed with 0.1 M HCl or NaCl solution. These salts are more slight soluble in the water. Therefore, they can be suitable for quantitative analysis of these cations or the chloride. These quantitative analyses are gravimetric analysis and the volumetric analysis such as Mohr, Fajans and Volhard Methods.

In this study, the solutions of problems have been done by two different methods that are known as by the formula and by the conversion factor in the calculations for the quantitative analysis in this context that gravimetric and volumetric analysis.

The solutions of chemical problems by the formula

In the solutions of chemical problems by the formula, firstly, the stoichiometric relation between mole number and mass and mole weight must be known. Secondly, the stoichiometric relation between the molarity of the solution and the mole number of solute and the volume of solution must be known.

A substance can be pure or not to be pure. The not pure substances have not the mole number although the pure substances such as the elements and the compounds have the mole number. The mole number of the compound or the element is calculated by their mass and mole weight by Eq. 1.

$$n_{A\,(mole)} = \frac{m_{A\,(g)}}{M_{A\,(g/mole)}} \tag{1}$$

If the mole number and the mole weight of A compound are known, its mass value is calculated from the mole number and the mole weight of compound by Eq. 2.

$$m_{A\,(g)} = n_{A\,(mole)} \text{ x } M_{A\,(g/mole)} \tag{2}$$

In a solution, the solute and the solvent have the mole numbers in spite the mole of the solution. But, the solution has a concentration in this context that the mole numbers of solute per liter of the solution. It is called as molarity. The molarity of the solution is calculated from the mole number of solute and the volume of solution by Eq. 3.

$$M_{Solution,\,(mole/L)} = \frac{n_{Solute\,(mole)}}{V_{Solution,\,(L)}} \tag{3}$$

If the volume and the molarity of solution are known, the mole number of solute is calculated from the volume and the molar concentration of solution by Eq. 4.

$$n_{Solute\,(mol)} = M_{Solution\,(mole/L)} \text{ x } V_{Solution\,(L)} \tag{4}$$

The solutions of the chemical problems by the conversion factor

The solution of the chemical problem by the conversion factor is used to decrease the error originated from the rounding of numbers in the calculations. In the calculations, the conversion factor is used to convert the quantity to another quantity. In the conversion factor, the quantities in the numerator and the denominator have equivalent units although they have different numerical value (for examples 1 mole Fe ≡ 56 g Fe or 1 m ≡ 100 cm). In the calculations by this method: (1) a converting factor can be written as two different forms such as $\frac{56\text{ g Fe}}{1\text{ mole Fe}}$ or $\frac{1\text{ mole Fe}}{56\text{ g Fe}}$; (2) the solution of the chemical problem by using converting factor must be always suitable to the Eq. 5; (3) in initial situation, the unit of the given quantity and the unit of the quantity in the conversion factor must be written. In the final situation, the unit of the quantity wanted must be obtained in the equation when the units are deleted; (4) in some problems, two or three conversion factors can be necessary to obtain the result wanted in the solution of problem.

$$\text{Wanted Quantity} = \text{the given quantity x the conversion factor} \qquad (5)$$

In this study, it is offered the three sub model for teaching how to calculate the quantity of precipitate. These sub models are consecutively called First Model, Second Model and Third Model. On the solved problems section, it is given the Examples 1-3 for First Model, the Examples 4-6 for Second Model and the Examples 7-9 for Third Model. All of examples are based on how to calculate the mass of chloride precipitate formed by the reactions of HCl solutions known molar concentrations and volumes and the M^{n+} cations (such as Ag^{1+}, Hg_2^{2+} or Pb^{2+}) solutions known molar concentrations and volumes. The volumes of HCl solutions are only given as adequately volume in all problems for first model.

Solved problems

In this section, it is given the nine problems and their solutions. These problems are three different types. Each type has a model for how to calculate the mass of the forming chloride precipitate and is exampled three different problems. The solutions of each problem have done using two different stoichiometric calculation methods.

Problems for first model

In this section, the examples 1-3 are given. The Example 1-3 is a model for how to calculate the mass of the chloride precipitate formed in the reaction carried out when the adequate volume of HCl solution known molar concentration is added into M^{n+} (such as Ag^{1+}, Hg_2^{2+} or Pb^{2+}) solution if it is known molar concentrations and volumes of M^{n+} solutions. In this model, the limiting reagent does not have to be determined to solute the problems of examples. Therefore, chemical calculations can be do according to molar concentration and volume of $M(NO_3)_n$.

Example 1. How many grams is the mass of AgCl precipitate formed when the 6.0 M HCl solution is adequately added its volume for the quantitative precipitation of Ag^{1+} in 3.0 mL of the 0.2 M $AgNO_3$ solution? (AgCl: 143.5 g/mole) (Note: The solubility of AgCl is going to be neglected on the calculation).

$$Ag^{1+} + Cl^{1-} \rightarrow AgCl\downarrow$$

The solution by formula method

This problem can be soluble on three simple steps.

Step 1. Let's calculate the mole of $AgNO_3$.

$$M_{AgNO3\ (mole/L)} = \frac{n_{AgNO3(mole)}}{V_{Solution(L)}} \Rightarrow n_{AgNO3(mole)} = M_{AgNO3\ (mole/L)} x V_{Solution(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4}\,\text{mole AgNO}_3$$

Step 2. Let's calculate the mole of AgCl.

$$n_{AgCl\,(mole)} = n_{AgNO3\ (mole)} = 6.0x10^{-4}\ \text{mole AgCl}$$

Step 3. Let's calculate the mass of AgCl.

$$n_{AgCl(mole/L)} = \frac{m_{AgCl(g)}}{M_{AgCl(g/mole)}} \Rightarrow m_{AgCl(g)} = n_{AgCl(mole)}\, xM_{AgCl(g/mole)}$$

$$= 6.0x10^{-4}\, x143.5 = 8.61x10^{-2}\ \text{g AgCl}$$

The solution by the conversion factor method

Step 1. Let's calculate the mass of AgCl by the using conversion factor.

$$?\ \text{g AgCl} = 3.0\ \text{mL x} \frac{1.0\ \text{L}}{1000\ \text{mL}} \text{x} \frac{0.2\ \text{mole AgNO}_3}{1.0\ \text{L}} \text{x} \frac{1.0\ \text{mole AgCl}}{1.0\ \text{mole AgNO}_3} \text{x} \frac{143.5\ \text{g AgCl}}{1.0\ \text{mole AgCl}}$$

$$= 8.61x10^{-2}\ \text{g AgCl}$$

Example 2. How many grams is the mass of Hg_2Cl_2 precipitate formed when the 6.0 M HCl solution is adequately added for the quantitative precipitation of Hg_2^{2+} in 3.0 mL of the 0.2 M $Hg_2(NO_3)_2$ solution? (Hg_2Cl_2: 272 g/mole) (Note: The solubility of Hg_2Cl_2 is going to be neglected on the calculation.)

$$Hg_2^{2+} + 2Cl^{1-} \rightarrow Hg_2Cl_2 \downarrow$$

The solution by formula method

This problem can be soluble on three simple steps.

Step 1. Let's calculate the mole of $Hg_2(NO_3)_2$.

$$M_{Hg2(NO3)2\ (mole/L)} = \frac{n_{Hg2(NO3)2(mole)}}{V_{Solution(L)}} \Rightarrow n_{Hg2(NO3)2(mole)} = M_{Hg2(NO3)2\ (mole/L)}\, xV_{Solution(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4}\ \text{mole}\ Hg_2(NO_3)_2$$

Step 2. Let's calculate the mole of Hg_2Cl_2.

$$n_{Hg2Cl2(mole)} = n_{Hg2(NO3)2\ (mole)} = 6.0x10^{-4}\ \text{mole}\ Hg_2Cl_2$$

Step 3. Let's calculate the mass of Hg_2Cl_2.

$$n_{Hg2Cl2(mole/L)} = \frac{m_{Hg2Cl2(g)}}{M_{Hg2Cl2(g/mole)}} \Rightarrow m_{Hg2Cl2\ (g)} = n_{Hg2Cl2(mole)}\, xM_{Hg2Cl2(g/mole)} = 6.0x10^{-4}\, x272$$

$$= 1.632x10^{-1}\ \text{g}\ Hg_2Cl_2$$

The solution by the conversion factor method

Step 1. Let's calculate the mass of Hg_2Cl_2 by the using conversion factor.

$$? \text{ g } Hg_2Cl_2 = 3.0 \text{ mL.x} \frac{1.0 \text{ L}}{1000 \text{ mL}} \text{ x } \frac{0.2 \text{ mole } Hg_2(NO_3)_2}{1.0 \text{ L}} \text{ x } \frac{1.0 \text{ mole } Hg_2Cl_2}{1.0 \text{ mole } Hg_2(NO_3)_2} \text{ x } \frac{272 \text{ g } Hg_2Cl_2}{1.0 \text{ mole } Hg_2Cl_2}$$

$$= 1.632 \text{ x } 10^{-1} \text{ g } Hg_2Cl_2$$

Example 3. How many grams is the mass of $PbCl_2$ precipitate formed when the 6.0 M HCl solution is adequately added for the quantitative precipitation of Pb^{2+} in 3.0 mL of the 0.2 M $Pb(NO_3)_2$ solution? ($PbCl_2$: 332 g/mole) (Note: The solubility of $PbCl_2$ is going to be neglected on the calculation.)

$$Pb^{2+} + 2Cl^{1-} \rightarrow PbCl_2 \downarrow$$

The solution by formula method
This problem can be soluble on three simple steps.

Step 1. Let's calculate the mole of $Pb(NO_3)_2$.

$$M_{Pb(NO3)2\ (mole/L)} = \frac{n_{Pb(NO3)2\,(mole)}}{V_{Solution(L)}} \Rightarrow n_{Pb(NO3)2\,(mole)} = M_{Pb(NO3)2\ (mole/L)} x V_{Soution(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4} \text{mole } Pb(NO_3)_2$$

Step 2. Let's calculate the mole of $PbCl_2$.

$$n_{PbCl2\,(mole)} = n_{Pb(NO3)2\ (mole)} = 6.0x10^{-4} \text{mole } PbCl_2$$

Step 3. Let's calculate the mass of $PbCl_2$.

$$n_{PbCl2(mole/L)} = \frac{m_{PbCl2(g)}}{M_{PbCl2(g/mole)}} \Rightarrow m_{PbCl2(g)} = n_{PbCl2(mole)} x M_{PbCl2(g/mole)} = 6.0x10^{-4} \text{ x } 332$$

$$= 1.992x10^{-1} \text{ g } PbCl_2$$

The solution by the conversion factor method

Step 1. Let's calculate the mass of $PbCl_2$ by the using conversion factor.

$$? \text{ g } PbCl_2 = 2.0 \text{ mL.x} \frac{1.0 \text{ L}}{1000 \text{ mL}} \text{ x } \frac{0.3 \text{ mol } Pb(NO_3)_2}{1.0 \text{ L}} \text{ x } \frac{1.0 \text{ mole } PbCl_2}{1.0 \text{ mole } Pb(NO_3)_2} \text{ x } \frac{332 \text{ g } PbCl_2}{1.0 \text{ mole } PbCl_2}$$

$$= 1.992x10^{-1} \text{ g } PbCl_2$$

Problems for second model

In this section, the examples 4-6 are given. The Example 4-6 is a model for how to calculate the mass of the chloride precipitate formed in the reaction when HCl solution is added into M^{n+} solution if it is known molar concentrations and volumes of both HCl and M^{n+} solutions. In this model, the limiting reagent must be determined to solute the example problems. But in the example problems, both $M(NO_3)_2$ and HCl react completely according to their molar concentrations and volumes. Two reagents do not also remain in solution when the reaction has completed. Therefore, chemical calculations can be do according to molar concentration and volume of $M(NO_3)_n$ or HCl solutions.

Example 4. How many grams is the mass of AgCl precipitate formed when 0.2 mL of the 6.0 M HCl solution is added for the quantitative precipitation of Ag^{1+} in 3.0 mL of the 0.2 M $AgNO_3$ solution? (AgCl: 143.5 g/mole) (Note: The solubility of AgCl is going to be neglected on the calculation.)

$$Ag^{1+} + Cl^{1-} \rightarrow AgCl\downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $AgNO_3$.

$$M_{AgNO3\ (mole/L)} = \frac{n_{AgNO3(mole)}}{V_{Solution(L)}} \Rightarrow n_{AgNO3(mole)} = M_{AgNO3\ (mole/L)} x V_{Solution(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4} \text{mole } AgNO_3$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)} x V_{Solution(L)}$$

$$= 6.0\ x1.0x\ 10^{-4} = 6.0x10^{-4} \text{mole HCl}$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $AgNO_3$ reacts completely with 1.0 mole of HCl to precipitate 1.0 mole of AgCl according to reaction. In the Example 4, at initial state, there are $6.0x10^{-4}$ mole of $AgNO_3$ and $6.0x10^{-4}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $AgNO_3$ reacts completely with $6.0x10^{-4}$ mole of HCl. Both $AgNO_3$ and HCl react completely in the solution when the reaction has completed. In this situation, the chemical calculation can do according to the mole of $AgNO_3$ or the mole of HCl. Therefore, it can be said that the limiting reagent is $AgNO_3$ or HCl because both $AgNO_3$ and HCl react completely when the reaction has completed.

Step 4. Let's calculate the mole of AgCl.

$$n_{AgCl\,(mole)} = n_{AgNO3\ (mole)} = 6.0x10^{-4}\,\text{mole AgCl}$$

Step 5. Let's calculate the mass of AgCl**.**

$$n_{AgCl\,(mole/L)} = \frac{m_{AgCl\,(g)}}{M_{AgCl\,(g/mole)}} \Rightarrow m_{AgCl\,(g)} = n_{AgCl\,(mole)}\,x\,M_{AgCl\,(g/mole)}$$

$$= 6.0x10^{-4}\,x143.5 = 8.61x10^{-2}\ \text{g AgCl}$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

It can be said that the limiting reagent is $AgNO_3$ or HCl because both $AgNO_3$ and HCl react completely when the reaction has completed.

Step 2. Let's calculate the mass of AgCl by the using conversion factor.

$$?\ \text{g AgCl} = 3.0\ \text{mL.x}\,\frac{1.0\ \text{L}}{1000\ \text{mL}}\,x\,\frac{0.2\ \text{mole AgNO}_3}{1.0\ \text{L}}\,x\,\frac{1.0\ \text{mole AgCl}}{1.0\ \text{mole AgNO}_3}\,x\,\frac{143.5\ \text{g AgCl}}{1.0\ \text{mole AgCl}}$$

$$= 8.61x10^{-2}\ \text{g AgCl}$$

Example 5. How many grams is the mass of Hg_2Cl_2 precipitate formed when the 0.2 mL of 6.0 M HCl solution is added for the quantitative precipitation of H_2^{2+} in 3.0 mL of the 0.2 M $Hg_2(NO_3)_2$ solution? (Hg_2Cl_2: 272 g/mole) (Note: The solubility of Hg_2Cl_2 is going to be neglected on the calculation.)

$$Hg_2^{2+} + 2Cl^{1-} \rightarrow Hg_2Cl_2 \downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $Hg_2(NO_3)_2$.

$$M_{Hg2(NO3)2\ (mole/L)} = \frac{n_{Hg2(NO3)2(mole)}}{V_{Solution(L)}} \Rightarrow n_{Hg2(NO3)2(mole)} = M_{(mole/L)}\ x\ V_{(L)} = 0.2\ x\ 3.0\ x\ 10^{-3}$$

$$= 6.0x10^{-4}\,\text{mole}\ Hg_2(NO_3)_2$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)} x V_{Solution(L)} = 6.0\ x 2.0 x\ 10^{-4} = 1.2x10^{-3} \text{ mole HCl}$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $Hg_2(NO_3)_2$ reacts completely with 2.0 mole of HCl to precipitate 1.0 mole of $PbCl_2$ according to reaction. In the Example 5, at initial state, there are $6.0x10^{-4}$ mole of $Hg_2(NO_3)_2$ and $1.2x10^{-3}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $Hg_2(NO_3)_2$ reacts completely with $1.2x10^{-3}$ mole of HCl. At final state, both $Hg_2(NO_3)_2$ and HCl react completely in the solution when the reaction has completed. In this situation, the chemical calculation can do according to the mole of $Hg_2(NO_3)_2$ or the mole of HCl. Therefore, it can be said that the limiting reagent is $Hg_2(NO_3)_2$ or HCl because both $Hg_2(NO_3)_2$ and HCl react completely when the reaction has completed.

Step 4. Let's calculate the mole of Hg_2Cl_2.

$$n_{Hg2Cl2(mole)} = n_{Hg2(NO3)2\ (mole)} = 6.0x10^{-4} \text{ mole } Hg_2Cl_2$$

Step 5. Let's calculate the mass of Hg_2Cl_2.

$$n_{Hg2Cl2(mole/L)} = \frac{m_{Hg2Cl2(g)}}{M_{Hg2Cl2(g/mole)}} \Rightarrow m_{Hg2Cl2(g)} = n_{Hg2Cl2(mole)} x M_{Hg2Cl2(g/mole)}$$

$$= 6.0x10^{-4} \text{ x } 272 = 1.632 \text{ x } 10^{-1} \text{ g } Hg_2Cl_2$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

It can be said that the limiting reagent is $Hg_2(NO_3)_2$ or HCl because both $Hg_2(NO_3)_2$ and HCl react completely when the reaction has completed.

Step 2. Let's calculate the mass of Hg_2Cl_2 by the using conversion factor.

$$?\text{ g } Hg_2Cl_2 = 3.0 \text{ mL.x } \frac{1.0\text{ L}}{1000\text{ mL}} \text{ x } \frac{0.2\text{ mole } Hg_2(NO_3)_2}{1.0\text{ L}} \text{ x } \frac{1.0\text{ mole } Hg_2Cl_2}{1.0\text{ mole } Hg_2(NO_3)_2} \text{ x } \frac{272\text{ g } Hg_2Cl_2}{1.0\text{ mole } Hg_2Cl_2}$$

$$= 1.632x10^{-1} \text{ g } Hg_2Cl_2$$

Example 6. How many grams is the mass of $PbCl_2$ precipitate formed when 0.2 mL of the 6.0 M HCl solution is added for the quantitative precipitation of Pb^{2+} in

3.0 mL of the 0.2 M $Pb(NO_3)_2$ solution? ($PbCl_2$: 332 g/mole) (Note: The solubility of $PbCl_2$ is going to be neglected on the calculation.)

$$Pb^{2+} + 2Cl^{1-} \rightarrow PbCl_2 \downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $Pb(NO_3)_2$.

$$M_{Pb(NO3)2\ (mole/L)} = \frac{n_{Pb(NO3)2(mole)}}{V_{Solution(L)}} \Rightarrow n_{Pb(NO3)2(mole)} = M_{Pb(NO3)2\ (mole/L)} x V_{Solution(L)} = 0.2x3.0x10^{-3} = 6.0x10^{-4}\,\text{mole}\ Pb(NO_3)_2$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)} x V_{Solution(L)} = 6.0\ x\ 2.0\ x\ 10^{-4} = 1.2x10^{-3}\,\text{mole HCl}$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $Pb(NO_3)_2$ reacts completely with 2.0 mole of HCl to precipitate 1.0 mole of $PbCl_2$ according to reaction. In the Example 6, at initial state, there are $6.0x10^{-4}$ mole of $Pb(NO_3)_2$ and $1.2x10^{-3}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $Pb(NO_3)_2$ reacts completely with $1.2x10^{-3}$ mole of HCl. At final state, both $Pb(NO_3)_2$ and HCl react completely in the solution when the reaction has completed. According to final state, the chemical calculation can do according to the mole of $Pb(NO_3)_2$ or the mole of HCl. Therefore, it can be said that the limiting reagent is $Pb(NO_3)_2$ or HCl because both $Pb(NO_3)_2$ and HCl react completely when the reaction has completed.

Step 4. Let's calculate the mole of $PbCl_2$.

$$n_{PbCl2\,(mole)} = n_{Pb(NO3)2\ (mole)} = 6.0x10^{-4}\,\text{mole}\ PbCl_2$$

Step 5. Let's calculate the mass of $PbCl_2$.

$$n_{PbCl2(mole/L)} = \frac{m_{PbCl2(g)}}{M_{PbCl2(g/mole)}} \Rightarrow m_{PbCl2(g)} = n_{PbCl2(mole)} x M_{PbCl2(g/mole)}$$

$$= 6.0x10^{-4} x332 = 1.992\ x\ 10^{-1}\ g\ PbCl_2$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

It can be said that the limiting reagent is $Pb(NO_3)_2$ or HCl because both $Pb(NO_3)_2$ and HCl react completely when the reaction has completed.

Step 2. Let's calculate the mass of $PbCl_2$ by the using conversion factor.

$$? \text{ g } PbCl_2 = 2.0 \text{ mL.x} \frac{1.0 \text{ L}}{1000 \text{ mL}} \text{ x} \frac{0.3 \text{ mole } Pb(NO_3)_2}{1.0 \text{ L}} \text{ x} \frac{1.0 \text{ mole } PbCl_2}{1.0 \text{ mole } Pb(NO_3)_2} \text{ x} \frac{332 \text{ g } PbCl_2}{1.0 \text{ mole } PbCl_2}$$

$$= 1.992 \text{ x } 10^{-1} \text{ g } PbCl_2$$

The problems for third model

In this section, the examples 7-9 are given. The Example 7-9 is a model for how to calculate the mass of the chloride precipitate formed in the reaction when the excess HCl solution is added into M^{n+} solution if it is known molar concentrations and volumes of both HCl and M^{n+} solutions. In this model, the limiting reagent must be determined to solute the problems. In the example problems, $M(NO_3)_n$ react completely and does not remain although HCl remains unreacted when the reaction has completed in the solution. Therefore, the limiting reagent is $M(NO_3)_n$ because $M(NO_3)_n$ reacts completely when the reaction has completed.

Example 7. How many grams is the mass of AgCl precipitate formed when 0.2 mL of the 6.0 M HCl solution is added for the quantitative precipitation of Ag^{1+} in 3.0 mL of the 0.2 M $AgNO_3$ solution? (AgCl: 143.5 g/mole) (Note: The solubility of AgCl is going to be neglected on the calculation.)

$$Ag^{1+} + Cl^{1-} \rightarrow AgCl \downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $AgNO_3$.

$$M_{AgNO3 \text{ (mole/L)}} = \frac{n_{AgNO3 \text{(mole)}}}{V_{Solution(L)}} \Rightarrow n_{AgNO3 \text{(mole)}} = M_{AgNO3 \text{ (mole/L)}} x V_{Solution(L)}$$

$$= 0.3x2.0x10^{-3} = 6.0x10^{-4} \text{ mole } AgNO_3$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)} x V_{Solution(L)}$$

$$= 6.0\ x2.0x\ 10^{-4} = 1.2x10^{-3}\ mole\ HCl$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $AgNO_3$ reacts completely with 1.0 mole of HCl to precipitate 1.0 mole of AgCl according to reaction. In the Example 7, at initial state, there are $6.0x10^{-4}$ mole of $AgNO_3$ and $1.2x10^{-3}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $AgNO_3$ reacts completely with $6.0x10^{-4}$ mole of HCl. At final state, $6.0x10^{-4}$ mole of HCl remains unreacted in the solution when the reaction has completed. According to final state, $AgNO_3$ react completely and does not remain in solution when HCl remains unreacted in the solution. Therefore, the limiting reagent is $AgNO_3$ because $AgNO_3$ react completely when the reaction has completed.

Step 4. Let's calculate the mole of AgCl.

$$n_{AgCl(mole)} = n_{AgNO3\ (mole)} = 6.0x10^{-4}\ mole\ AgCl$$

Step 5. Let's calculate the mass of AgCl**.**

$$n_{AgCl(mole/L)} = \frac{m_{AgCl(g)}}{M_{AgCl(g/mole)}} \Rightarrow m_{AgCl(g)} = n_{AgCl(mole)} x\ M_{AgCl(g/mole)}$$

$$= 6.0x10^{-4}\ x143.5 = 8.61x10^{-2}\ g\ AgCl$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

The limiting reagent is $AgNO_3$ because $AgNO_3$ react completely when the reaction has completed.

Step 2. Let's calculate the mass of AgCl**.**

$$?\ g\ AgCl = 2.0\ mL.x\ \frac{1.0\ L}{1000\ mL}\ x\ \frac{0.3\ mole\ AgNO_3}{1.0\ L}\ x\ \frac{1.0\ mole\ AgCl}{1.0\ mole\ AgNO_3}\ x\ \frac{143.5\ g\ AgCl}{1.0\ mole\ AgCl}$$

$$= 8.61x10^{-2}\ g\ AgCl$$

Example 8. How many grams is the mass of Hg_2Cl_2 precipitate formed when the 0.4 mL of 6.0 M HCl solution is added for the quantitative precipitation of Hg_2^{2+} in 3.0 mL of the 0.2 M $Hg_2(NO_3)_2$ solution? (Hg_2Cl_2: 272 g/mole) (Note: The solubility of Hg_2Cl_2 is going to be neglected on the calculation.)

$$Hg_2^{2+} + 2Cl^{1-} \rightarrow Hg_2Cl_2 \downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $Hg_2(NO_3)_2$.

$$M_{Hg2(NO3)2\ (mole/L)} = \frac{n_{Hg2(NO3)2(mole)}}{V_{Solution(L)}} \Rightarrow n_{Hg2(NO3)2(mole)} = M_{(mole/L)} x V_{(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4} \text{mole } Hg_2(NO_3)_2$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)} x V_{Solution(L)}$$

$$= 6.0\ x4.0x\ 10^{-4} = 2.4x10^{-3} \text{mole HCl}$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $Hg_2(NO_3)_2$ reacts completely with 2.0 mole of HCl to precipitate 1.0 mole of Hg_2Cl_2 according to reaction. In the Example 8, at initial state, there are $6.0x10^{-4}$ mole of $Hg_2(NO_3)_2$ and $2.4x10^{-3}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $Hg_2(NO_3)_2$ reacts completely with $1.2x10^{-3}$ mole of HCl. At final state, $1.2x10^{-3}$ mole of HCl remains unreacted in the solution when the reaction has completed. According to final state, $Hg_2(NO_3)_2$ react completely and does not remain in solution when HCl remains unreacted in the solution. Therefore, the limiting reagent is $Hg_2(NO_3)_2$ because $Hg_2(NO_3)_2$ react completely when the reaction has completed.

Step 4. Let's calculate the mole of Hg_2Cl_2.

$$n_{Hg2(NO3)2\ (mole)} \equiv n_{Hg2Cl2\ (mole)} \equiv 6.0x10^{-4} \text{mole } Hg_2Cl_2$$

Step 5. Let's calculate the mass of Hg_2Cl_2.

$$n_{Hg2Cl2\ (mole)} = \frac{m_{Hg2Cl2\ (mole)}}{M_{Hg2Cl2(g/mole)}} \Rightarrow m_{Hg2Cl2\ (g)} = n_{Hg2Cl2(mole)}\ x\ M_{Hg2Cl2\ (g/mole)}$$

$$= 6.0 \text{ x } 10^{-4} \text{ x } 272 = 1.632 \text{ x } 10^{-1}\ g\ Hg_2Cl_2$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

The limiting reagent is $Hg_2(NO_3)_2$ because $Hg_2(NO_3)_2$ react completely when the reaction has completed.

Step 2. Let's calculate the mass of Hg_2Cl_2.

$$?\ g\ Hg_2Cl_2 = 3.0\ mL.x\ \frac{1.0\ L}{1000\ mL}\ x\ \frac{0.2\ mole\ Hg_2(NO_3)_2}{1.0\ L}\ x\ \frac{1.0\ mole\ Hg_2Cl_2}{1.0\ mole\ Hg_2(NO_3)_2}\ x\ \frac{272\ g\ Hg_2Cl_2}{1.0\ mole\ Hg_2Cl_2}$$

$$= 1.632 \text{ x } 10^{-1}\ g\ Hg_2Cl_2$$

Example 9. How many grams is the mass of $PbCl_2$ precipitate formed when 0.4 mL of the 6.0 M HCl solution is added for the quantitative precipitation of Pb^{2+} in 3.0 mL of the 0.2 M $Pb(NO_3)_2$ solution? ($PbCl_2$: 332 g/mole) (Note: The solubility of $PbCl_2$ is going to be neglected on the calculation.)

$$Pb^{2+} + 2Cl^{1-} \rightarrow PbCl_2 \downarrow$$

The solution by formula method

This problem can be soluble on five simple steps.

Step 1. Let's calculate the mole of $Pb(NO_3)_2$.

$$M_{Pb(NO3)2\ (mole/L)} = \frac{n_{Pb(NO3)2(mole)}}{V_{Solution(L)}} \Rightarrow n_{Pb(NO3)2(mole)} = M_{Pb(NO3)2\ (mole/L)}\, xV_{Solution(L)}$$

$$= 0.2x3.0x10^{-3} = 6.0x10^{-4} \text{ mole } Pb(NO_3)_2$$

Step 2. Let's calculate the mole of HCl.

$$M_{HCl\ (mole/L)} = \frac{n_{HCl,(mole)}}{V_{Solution(L)}} \Rightarrow n_{HCl(mole)} = M_{HCl\ (mole/L)}\, xV_{Solution(L)}$$

$$= 6.0 \text{ x } 4.0 \text{ x } 10^{-4} = 2.4x10^{-3} \text{ mole HCl}$$

Step 3. Let's determine the limiting reagent.

1.0 mole of $Pb(NO_3)_2$ reacts completely with 2.0 mole of HCl to precipitate 1.0 mole of $PbCl_2$ according to reaction. In the Example 9, at initial state, there are $6.0x10^{-4}$ mole of $Pb(NO_3)_2$ and $2.4x10^{-3}$ mole of HCl in solution. In the reaction, $6.0x10^{-4}$ mole of $Pb(NO_3)_2$ reacts completely with $1.2x10^{-3}$ mole of HCl. At final state, $1.2x10^{-3}$ mole of HCl remains unreacted in the solution when the reaction has completed. According to final state, $Pb(NO_3)_2$ react completely and does not remain in solution when HCl remains unreacted in the solution. Therefore, the limiting reagent is $Pb(NO_3)_2$ because $Pb(NO_3)_2$ react completely when the reaction has completed.

Step 4. Let's calculate the mole of $PbCl_2$.

$$n_{Pb(NO3)2\ (mole)} \equiv n_{PbCl2\ (mole)} \equiv 6.0x10^{-4}\,\text{mole PbCl}_2$$

Step 5. Let's calculate the mass of $PbCl_2$.

$$n_{PbCl2\ (mole)} = \frac{m_{PbCl2,(mole)}}{M_{PbCl2(g/mole)}} \Rightarrow m_{PbCl2\ (g)} = n_{PbCl2(mole)}\,x\,M_{PbCl2\ (g/mole)}$$

$$= 2.0\ x\ 10^{-4}\ x\ 332 = 1.992\ x\ 10^{-1}\,g\ PbCl_2$$

The solution by the conversion factor method

Step 1. Let's determine the limiting reagent.

The limiting reagent is $Pb(NO_3)_2$ because $Pb(NO_3)_2$ react completely when the reaction has completed.

Step 2. Let's calculate the mass of $PbCl_2$.

$$?\,g\ PbCl_2 = 2.0\ mL.x\,\frac{1.0\ L}{1000\ mL}\,x\,\frac{0.3\ mole\ Pb(NO_3)_2}{1.0\ L}\,x\,\frac{1.0\ mole\ PbCl_2}{1.0\ mole\ Pb(NO_3)_2}\,x\,\frac{332\ g\ PbCl_2}{1.0\ mole\ PbCl_2}$$

$$= 1.992\ x\ 10^{-1}\ g\ PbCl_2$$

Discussion

On the evaluation the nine example problems and their solutions given in this study, it has been carried out for modeling how to apply by two calculation methods in the reaction between first group cations and the HCl solution. By this way, it can be taught that the first group cations are Ag^{1+}, Pb^{2+} and Hg_2^{2+} ions and their group reagent is HCl solution in this context the qualitative analysis.

In the first type model given in the 1-3 examples, it was modeled the teaching how to calculate the mass and mole number of MCl_n salt precipitated and the mole number of ion formed from reagent in this context the molarity and volume of reagent solution. In addition, in the second and third models, it was modeled the teaching how to determine the limiting reagent when the molarities and the volumes of two reagent solutions are given in the problems. Therefore, it can be said that the three models given in this study are suitable to teach how to calculate the mass and mole number of MCl_n salt precipitated in this context the molarities and the volumes of the reagent solutions. In addition, it can also be taught how to determine the limiting reagent.

In all the example problems, the net ion reactions were especially given to the place of stoichiometry reactions. On the teaching, it is desired the understanding of the students   to the linkage between the mole number of reagent and its ion in the net ion reaction when the example problems are solved in the class. For example, the 1 mol $AgNO_3$ is the equivalent to the 1 mol Ag^{1+} in net ion reaction. Therefore, this information is the meaningful and the important to calculate the mass of the precipitate in the solutions of problems.

These type problems can be solved by one from the two problem solution methods given in this study. It can be taught both the formula method and the conversion methods in this context stoichiometry education. It can be said that the students educated by formula method are more successful than the student educated by the conversion factor method in our university. Therefore, the teaching of the solution by formula method must be preferred to the solution by the conversion factor methods in stoichiometry education.

Conclusions

This study was carried out to model how the stoichiometric calculations can be done to determine hypothetically the quantity of chloride precipitate and the limiting reagent in reactions occurred between HCl with first group cations by the nine problems and their solutions. In light of these studies, conclusions are as follows: (a) These problems and their solutions is a model for the teaching of the linkage between qualitative analysis, quantitative analysis and chemical calculation in analytical chemistry education of the candidates of science education teacher in undergraduate; (b) The students can be learned being of that Ag^{1+}, Hg_2^{2+} and Pb^{2+} cations are the first group cations and their group reagent is 0.1 M HCl solution in this context of qualitative analysis of inorganic compounds; (c) The students can be gained experience in doing stoichiometric calculations in this context of the masses and mole numbers of salts precipitated, mole numbers, the volumes and the molarities of reagents on the precipitating reactions of salts which have limited solubility in water; (d) It can be taught how to determine the limiting reagent in a chemical reaction.

REFERENCES

Blake, B. (2003). Solubility rules: three suggestions for improved understanding. *J. Chem. Educ. 80,* 1348 − 1350.

De Meo, S. (2002). Using limiting-excess stoichiometry to introduce equilibrium calculations: a discrepant event laboratory activity involving precipitation reactions. *J. Chem. Educ. 79*, 474 − 475.

Ergül, S. (2015). Three hypothetical problems for quantitative precipitation. *Chemistry, 24,* 247 − 255.

Ricci, R.W. & Ditzler, M.A. (1991). Discovery chemistry: a laboratory centered approach to teaching general chemistry. *J. Chem. Educ. 68*, 228 − 231.

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