12.5: Stoichiometry of Aqueous Reactions

Introduction

At the beginning of this Chapter we covered stoichiometry of reactions where everything was a solid, and we used the mass and formula weight to calculate the moles of reactants or products consumed or produced. For a reaction where two chemicals interact with each other they must come into contact with each other if the reaction is going to proceed. One way of enabling this mobility is to dissolve the reactants into a solvent creating a solution. Unless you have a pure substance, you can not use mass to measure the number of particles, as you are weighting both the solvent and solute(s). So if you have a solution, you need to know the concentration, and the most common way of representing chemical concentrations is the molarity.

Solid phase:

$$n(moles) = \frac{m(g)}{fw(\frac{g}{mol}} \tag{12.5.1}$$

$$\color{red}{n = \frac{m}{fw}} \tag{12.5.2}$$

Aqueous phase (solute concentration):

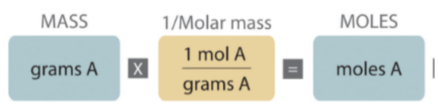
$$n(moles) = M\left(\frac{mol}{L}\right)V(L) \tag{12.5.3}$$

$$\color{red}{n = MV} \tag{12.5.4}$$

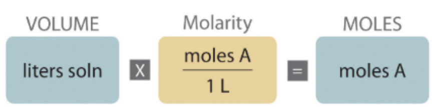
where,
n = moles
m = mass
V = Volume
fw = formula weight (molar mass)

So now we can calculate the moles of a pure substance if we weigh it's mass and know it's molar mass, or if we measure its volume and know it's concentration (Molarity).

If given a solid, you need to know its molar mass



If given a solute, you need to know its concentration (molarity)



Solution Stoichiometry

In sections 4.1 and 4.2 we calculated theoretical yield, limiting reagent and excess reagents for reactions where all chemical species were described as solids where we measured the mass. Now that we have a way to describe solute concentrations (Molarity) we can extend these to include solutions where we measure the volume. Lets look at the reaction of adding a solid soluble salt to an aqueous solution

Dissolving 10.0 g of Copper(II)sulfate into 500.0 mL of 0.100 M sodium phosphate

? Exercise 12.5.1

What are the formulas of the reactants when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate? (see video 12.5.1)

Answer

$CuSO_4$(s) and Na_3PO_4(aq)

? Exercise 12.5.2

What are the formulas and phases of the products when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate?(see video 12.5.1)

Answer

Na_2SO_4(aq) and $Cu_3(PO_4)_2$(s)

Exercise 12.5.3

Write the balanced equation when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate?(see video 12.5.1)

Answer

$3CuSO_4(aq) + 2Na_3PO_4(aq) \text{ --> } 3Na_2SO_4(aq)$ and $Cu_3(PO_4)_2(s)$

NOTE: We added copper(II)sulfate as a solid, but it dissolved (see solubility rules, section 3.4.2.1), and so it should be treated as aqueous when writing the equation

Video: 12.5.1: 3'54" YouTube identifying reactants, products, phases and balancing the equation for the dissolution of 10 g of copper(II) sulfate into 500.0 mL of 0.100 M sodium phosphate (https://youtu.be/qdtiFATDMdU).

Calculating the Theoretical Yield for the mass of precipitate formed

Example 12.5.4

Calculate the theoretical yield for the mass of precipitate formed when 10.0 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate.

Solution

See video 12.5.2 for the solution of this problem, and video 12.5.3 for a deeper explanation of the fast technique used in video 2. Note how we set up the equation by writing out the given data under each species, along with the moles that we need to calculate with that data. We calculate for the moles of each reactant (n), divide by its storichiometric coefficient, and the smallest number is the limiting reagent. We then proceed and calculate the mass of copper(II)phosphate formed.

$$\underset{\substack{n= \\ m=10.0g \\ fw=159.61g/mol}}{3CuSO_4(s)} + \underset{\substack{n= \\ M=0.100mol/l \\ V=500.0ml}}{2Na_3PO_4(aq)} \rightarrow \underset{\substack{m=? \\ fw=380.58g/mol}}{Cu_3(PO_4)_2(s)} + 3Na_2SO_4(aq) \tag{12.5.5}$$

at 2'25" into video 12.5.2 we calculated the limiting reagent, which was copper(II)Sulfate and thus based the yield on its consumption. The overall equation is

$$10.0gCuSO_4(s)\left(\frac{molCuSO_4}{159.69g}\right)\left(\frac{1molCu_3(PO_4)_2}{3molCuSO_4}\right)\left(\frac{380.58gCu_3(PO_4)_2(s)}{mol}\right) = 7.95gCu_3(PO_4)_2(s) \tag{12.5.6}$$

Note, the above equation is not used in the fast technique, but is used in video 12.5.3 when we explain the fast technique

Video: 12.5.2: 3'30" YouTube video calculating the mass precipitate formed by complete consumption of the limiting reagent for the dissolution of 10 g of copper(II) sulfate into 500.0 mL of 0.100 M sodium phosphate (https://youtu.be/Vh3Je39bgQc)

Video: 12.5.3: The fast technique in video 12.5.2 explained in more detail (https://youtu.be/5Qlo1bi1uzE).

Calculating excess reagents

Since the copper sulfate is the limiting reagent we can calculate the amount of excess sodium phosphate

✔ Example 12.5.2: Excess Reagent

Calculate the concentration (molarity) of excess phosphate when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate (note: the real reaction is expressed by the net ionic equation:

$$3Cu^{+2}(aq) + 2PO_4^{-3}(aq) \rightarrow Cu_3(PO_4)_2(s) \tag{12.5.7}$$

Solution

see Video 12.5.4

First calculate moles excess phosphate

$$\text{Initial moles} - \text{amount consumed by reaction with limiting reagent} \tag{12.5.8}$$

$$0.050 mol PO_4^{-3} - 0.06265 mol Cu^{+2}\left(\frac{2\ mol\ PO_4^{-3}}{3\ mol\ Cu^{+2}}\right) = 0.0082 mol PO_4^{-3}$$

then divide into total volume

$\frac{0.0082 mol PO_4^{-3}}{0.500 l} = 0.016 M PO_4^{-3}(aq)$

Video 12.5.4: Determining the excess phosphate when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate https://youtu.be/xsp1_BADnqA).

Calculating Concentration of Spectator Ions

For the reaction that occurs when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate we have calculated the theoretical yield

Example 12.5.3 Spectator Ion Concentrations

Calculate spectator ion concentrations when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate

Solution

See video 12.5.5 for the solution to this problem. There are several ways you can set this up. In calculating the limiting reagent we determined the moles of each reactant and so that would be a logical place to start

$$\underset{\substack{n=\frac{m(g)}{fw(g/mol)}=\frac{10.0g}{159.61g/m0l} \\ n=0.06265mol}}{3CuSO_4(s)} + \underset{\substack{n=MV=(0.100mol/l)(0.5000l \\ n=0.0500mol}}{Na_3PO_4(aq)} \rightarrow Cu_3(PO_4))2(s) + 3Na_2SO_4(aq) \tag{12.5.9}$$

$$\frac{molSO_4^{-2}}{V_{total}} = \frac{0.06265molCuSO_4\left(\frac{1molSO_4^{-2}}{molCuSO_4}\right)}{0.500l} = 0.125M \tag{12.5.10}$$

$$\frac{molNa^{+}}{V_{total}} = \frac{0.0500molNa_3PO_4\left(\frac{3molNa^{+}}{molNa_3PO_4}\right)}{0.500l} = 0.300M \tag{12.5.11}$$

Video 12.5.5: 2'44" YouTube calculating the spectator ion concentration when 10 g of copper(II) sulfate is dissolved into 500.0 mL of 0.100 M sodium phosphate.

Test Yourself

Homework: Section 8.3

Graded Assignment: Section 8.3

Exercise 12.5.4

Consider the reaction of sodium phosphate and barium chloride, where 25.00 ml of 0.8000M Na_3PO_4 is mixed with 25.00ml of 0.1000M $BaCl_2$ (and the final volume is 50.00 ml, that is there is no change in volume upon mixing).

a. What is the limiting reagent?
b. What is the identity and mass of precipitate formed?
c. What is the concentration of the sodium spectator ion?
d. What is the concentration of the excess phosphate?

Answer a

$BaCl_2$

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Answer b

$0.5016 g Ba_3(PO_4)_2$

$$0.002500 mol BaCl_2 \left(\frac{1 mol Ba_3(PO_4)_3)}{3 mol BaCl_2}\right)\left(\frac{601.93 g Ba_3(PO_4)_2)}{mol}\right) = 0.5016 g Ba_3(PO_4)_2$$

Answer c

0.1200M

$M_f V_f = M_i V_i$

$M_F = \frac{M_i V_i}{V_f}$

$$\frac{0.8000 mol/L\ Na_3PO_4 \left(\frac{3 mol Na^+}{mol Na_3PO_4}\right) 0.02500 L\ Na_3PO_4}{0.02500 L + 0.02500 L} = 1.200 M Na^+$$

Answer d

$$mol_{excess}\ PO_4^{-3} = mole_{initial} - mol_{consumed}$$

$$0.8000 mol Na_3PO_4/L \left(\frac{1 mol PO_4^{-3}}{mol Na_3PO_4}\right) 0.02500 L - \left(0.100 mol/L\ BaCl_2 \left(\frac{1 mol Ba^{+2}}{mol BaCl_2}\right) 0.02500 L \left(\frac{2 mol PO_4^{-3}}{3 mol Ba^{+2}}\right)\right) = 0.01833 mol PO_4^{-3}$$

$$Concentration = \frac{mol_{excess}\ PO_4^{-3}}{V_T} = \frac{0.01833 mol PO_4^{-3}}{0.02500 L + 0.02500 L} = 0.3667 M\ PO_4^{-3}$$

Contributors and Attributions

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