Chem 111 – Experiment 4 – Simulation – Limiting Reactant and Excess Reactant

Background

Material Amounts in Chemical Reactions

In a reaction where the reactants are not present in a stoichiometric ratio, the amount of product produced is determined by the amount of the reactant that is fully consumed in the reaction first. This reactant is called the liming reactant (or limiting reagent). It is the amount of this reactant that is used to calculate the amount of product, just like a bread recipe can be adjusted based on the amount of an ingredient that's in short supply.

At this stage from the simulations that we have done to this point we known that in stoichiometry the absolute key is the balanced chemical equation. Without it we can only observe, with it we can calculate anything that we need to. Take for example the balanced chemical equation for the reaction given below: -

$$\mathbf{Mg(s) + 2\ HCl(aq) = MgCl_2(aq) + H_2(g)}$$

Let's assume that we start with a certain number of grams of Mg(s). With just that information and the balanced chemical equation we can easily determine the number of moles of HCl(aq) required to react with the Magnesium.

First up we would simply convert the grams of Mg(s) to moles of Mg(s): -

$$\text{\# moles Mg(s)} = \frac{\text{\#g of Mg(s)}}{\text{Molar Mass of Mg(s)}}$$

Now it is simply using the stoichiometric coefficient from the balanced chemical equation to convert our moles of Mg(s) to moles of HCl(aq):-

$$\frac{\text{\# moles of Mg(s)}}{} \left| \frac{\text{2 moles HCl(aq)}}{\text{1 mole Mg (s)}} \right. = \text{\# moles HCl(aq)}$$

The only variation on this is that often, when working in the lab, once we have found the number of moles – in this case HCl(aq) – we may need to convert the # moles back to grams. This is just a variation of our very first step in this process:-

$$\text{\# moles HCl(aq)} = \frac{\text{\#g of HCl(aq)}}{\text{Molar Mass of HCl(aq)}}$$

No rocket math here to rearrange this to give simply that: -

$$\text{\#g of HCl(aq) = \# moles of HCl(aq) x Molar Mass of HCl}$$

Determine the Limiting Reactant through Calculations

In this reaction we will be reacting aqueous solutions of $Cu(SO_4)$ and Na_2S according to the balanced chemical equation:

$$\mathbf{Cu(SO_4)(aq) + Na_2S(aq) = Na_2SO_4(aq) + CuS(s)}$$

The thing about it is that since this is a balanced chemical equation then all we need is to know the quantity of one of the compounds in order to calculate the needed quantities (of the reactants) and the expected quantities of the products.

So a red flag should go off in your head when you are given the quantities of two of the compounds. The red *flag – check for a Limiting Reactant. In this case we are given the volume and Molarity of the two reactants – $Cu(SO_4)(aq)$ and $Na_2S(aq)$.*

The trick here is to use each individual reactant and just use it to calculate the number of moles of a product expected, we will use CuS(s). We will then look at the two numbers and see if they are different. Different – we have a Limiting Reactant.

Since these are solution and we need to determine the moles we will be using a slight manipulation of Molarity to determine the number of moles.

$$\mathbf{M = \frac{\#moles}{V(L)}}$$

Which with a small manipulation gives:-

$$\mathbf{\#moles = M \times V(L)}$$

a) So let's first take $Cu(SO_4)(aq)$ in which we are given the Molarity and the Volume.

#moles $Cu(SO_4)$ = M x V(l)

Now lets use the balanced chemical equation to convert this to moles of CuS(s). I know the stoichiometric coefficients are 1:1 but I want you to get into the habit of doing the following as they may not always be 1:1.

$$\mathbf{\frac{\#\ moles\ of\ Cu(SO_4)}{} \left| \frac{1\ mole\ CuS}{1\ mole\ Cu(SO_4)} \right. = \#\ moles\ CuS}$$

b) Lets now repeat this process but this time using $Na_2S(aq)$

c) Now just look at the #moles of CuS(s) that you calculated from each. The one that gave you the smaller number of moles of CuS(s) is the Limiting Reactant. Easy?

Any subsequent calculations that you may be asked should use this Limiting Reactant and ignore the other.

Determine the Limiting Reactant Through Experimentation

It is also possible to qualitatively determine the excess reactant experimentally. The resulting mixture after a reaction can be further reacted with test reagents to determine which reactant has not been fully consumed and therefore is present in excess. To do this, a set of reagents is needed that can identify the two reactants, but not react with the products formed.

In this simulation you will be reacting copper(II) sulfate with sodium sulfide to produce copper(II) sulfide, a black precipitate. After the reaction the solution can be tested to determine if there is an excess of either $CuSO_4$ or Na_2S using a test solution that contains zinc sulfate and ammonia.

How Does The Test Solution Work?

In aqueous solution, ammonia reacts with water to form NH_4^+ and OH^- ions. The test solution contains a large enough quantity of ammonia that it remains in excess. Adding $ZnSO_4$ to the aqueous NH_3 produces zinc hydroxide, $Zn(OH)_2$, a white gelatinous precipitate, according to the balanced equation below.

$$Zn^{+2}(aq) + 2\ OH^{-}(aq) = Zn(OH)_2(s)$$

The zinc hydroxide, in turn, reacts with the excess ammonia in the solution to form a colorless zinc ammonia complex, $[Zn(NH_3)_4]^{2+}$.

$$Zn(OH)_2(s) + 4\ NH_3(aq) = [Zn(NH_3)_4]^{2+}(aq) + 2\ OH^{-}(aq)$$

Altogether, the colorless test solution contains $[Zn(NH_3)_4]^{2+}$ and NH_3 and SO_4^{2-}. This test solution reacts with the excess $CuSO_4$ or excess Na_2S in two different ways which yield two very different colors.

$$Cu^{2+}(aq) + 4\ NH_3(aq) = [Cu(NH_3)_4]2^{+}(aq)$$

$$S^{2-}\ (aq) + Zn^{2+}(aq) = ZnS(s)$$

Each product from these last two reactions is a distinctive color. So once your reactions are done you will add this test solution to the test solution and depending on the color you tell whether it is Cu^{2+} or S^{2-} that still remains in the solution and thus by default determine the limiting reagent.
This will make more sense once you have done one reaction in Experiment 4b

About This Lab

In this lab, you will combine solutions of copper(II) sulfate ($CuSO_4$) and sodium sulfide (Na_2S) to produce copper(II) sulfide (CuS). You will combine the two reagents in various ratios so that sometimes the Na_2S will be the limiting reagent and sometimes the $CuSO_4$ will be the limiting reagent. You will use a zinc sulfate and ammonia test solution to identify the excess and limiting reagents.

Open the simulation by clicking on the virtual lab icon shown on the left on the Hayden-McNeil Web Site. The simulation will launch in a new window.

You may need to move or resize the window in order to view both the Procedure and the simulation at the same time.

Follow the instructions in the Procedure to complete each part of the simulation. When instructed to record your observations, record data, or complete calculations, record them for your own records in order to use them later to complete the post-lab assignment.

Procedure

Experiment 4a – Prepare the Test Solution and Test Standards

1. Take **two test tubes** and one **10 mL graduated cylinder** from the **Containers shelf** and place them on the workbench.

2. Take **0.1 M copper(II) sulfate** from the **Materials shelf** and measure **6 mL into the graduated cylinder**. **Double-click to read** and **record the exact volume at the meniscus**. **Transfer the liquid** to the **first test tube** and **record the color of the solution** to reference later.

3. Take **0.1 M sodium sulfide** from the **Materials shelf** and measure **6 mL into the graduated cylinder**. **Double-click to read** and **record the exact volume at the meniscus**. **Transfer the liquid** to the **second test tube** and **record the color of the solution** to reference later.

4. Take **one 50 mL beaker and one 50 mL graduated cylinder** from the **Containers shelf**. Measure **20 mL 6 M ammonia in the graduated cylinder**, **recording the exact volume at the meniscus**, then **transfer to the beaker**.

5. Take **0.4 M zinc sulfate** from the **Materials shelf**. Use the **graduated cylinder to measure 20 mL**, then **transfer to the beaker**. *You have now prepared the test solution*.

6. Take the **test solution** and **pour 2 mL** into **each of the two test tubes**. **Record any color changes** and **whether a precipitate forms**.

7. The **first test tube** shows **what an excess of copper(II) sulfate looks like**, and the **second test tube shows what an excess of sodium sulfide looks like**. These are **your standards against which to compare other samples**. *Double click on each test tube and label the tube for reference*.

Experiment 4b – Test Different Ratios of Copper(II) Sulfate and Sodium Sulfide

1. Take the **balance** from the **Instruments shelf** and place it on the workbench.

2. Take a **clean test tube** from the **Containers shelf** and **place it on the balance**. **Record** the **mass** of the **empty test tube**.

3. **Measure 5 mL 0.1 M copper sulfate into the graduated cylinder**, then **transfer to the test tube**. *Note: In a classroom laboratory, you would remove the container from the balance before you add any chemicals or solutions. Filling the container separately prevents any spills, sprays, or splashes that might affect your measurements when they land on the balance.*

4. Take **0.1 M sodium sulfide from the Materials shelf**. Measure **1 mL in the graduated cylinder**, then **transfer to the test tube**. Note and **record the colors of the solution** as well as the **precipitate**.

5. Take another **clean test tube** from the **Containers shelf**, and place it on the workbench.

6. **Decant the liquid supernatant** (*the liquid lying above the solid residue*) from the first test tube used in Part 2 into it. *To do this, move the original test tube onto the new one and select the Decant option*. The first test tube now contains just the precipitate.

7. **Add 2 mL of test solution** from **the beaker** to the **test tube with the liquid supernatant**. **Compare it with the standards to see which chemical compound is present in excess**. **Record** this **result**.

8. **Weigh the test tube with precipitate** and **record the mass**.

9. *Clear your station by emptying the test tubes containing supernatant and precipitate in the waste, then placing in the sink*. **Do not throw out your standards or your test solution**.

10. **Repeat steps 2 – 9** *four times*, **replacing the amounts in steps 3 and 4** with the **amounts listed in the table below.**

Trial	**$CuSO_4$ (mL)**	**Na_2S (mL)**
2	4	2
3	3	3
4	2	4
5	1	5

11. Clear the bench of all materials, containers, and instruments, then use the **Report File** that you downloaded from the **General Chemistry web site**. When completed **send it to your TA.**