rr

Owen Brake

Calculating Percentage Yield using Molar Quantities

The Single Displacement of Copper(ii) Sulfate and Iron

1. Saxena  
   2018-05-19

Contents

[Introduction 2](#_Toc514507854)

[Purpose 2](#_Toc514507855)

[Background Information 2](#_Toc514507856)

[Calculations 3](#_Toc514507857)

[1. Write the balanced chemical equation for the reaction. 3](#_Toc514507858)

[2. What mass of Cu(s) can be prepared by the reaction of iron wool 4](#_Toc514507859)

[Materials List 4](#_Toc514507860)

[Procedure: 4](#_Toc514507861)

[Hypothesis and Rationale 5](#_Toc514507862)

[Experimental Results 5](#_Toc514507863)

[Discussion 7](#_Toc514507864)

[Sources of Error 8](#_Toc514507865)

[Conclusion 9](#_Toc514507866)

[References 11](#_Toc514507867)

Introduction:

The yield for a chemical reaction, the relationship between that yield, and the balanced

equation representing the reaction are very important to chemists. Not only does a laboratory

chemistry investigation require an understanding of such concepts, but the chemical industry also

depends on percent yield principle in manufacturing of chemical products.

Stoichiometry is the study of quantities in chemical reactions. The Stoichiometry of a reaction is

based on the mole. The coefficients in the balanced equation represent the relative number of moles of

substances that react or are formed in the reaction.

For practical reasons, the quantities of the reactants used in a reaction are generally not in the

same mole proportions as the balanced chemical equation. It is important to be able to predict how

much product will form under certain conditions.

Purpose:

In this experiment, you will use iron wool and an aqueous solution of copper (II) sulfate in order to

synthesize Cu(s). A single displacement reaction will take place, the products being iron(III)sulfate and

copper metal. The balanced equation for this reaction is:

3CuSO4 ●5H2O (s) + 2Fe(s) + H2O(aq) → 3Cu(s) + Fe2(SO4)3 (aq) + 6H2O(aq)

and the expected percentage yield is 95%. The percentage yield is 95% based off prior research and comparisons to similar experiments. The limiting reactant in this equation is the copper(ii) sulfate pentahydrate. This is the limiting reactant as it should be completely used up to result in the most copper.

## Background Information

Copper is a substance that has been harvested and utilized for millennia. It is one of the first metals ever to be used by early human beings. Early humans used copper as currency, jewelry and tools. Like early humans, modern humans use copper extensively and is integral to modern life. Copper is used almost universally in wiring, copper is highly conductive while also being relatively cheap to produce compared to similarly conductive metals such as silver which are expensive to extract. Copper is used in plumbing due to its affordability to extract and its corrosion resistance. Copper is also used extensively in metal alloy, when mixed with zinc it can create brass, when mixed with tin it creates bronze, these alloys are then used for so many different applications as it combines the properties of copper with other metals. Though copper is prevalent in modern society it also has its dangers, exposure to high doses of copper can have severe negative health effects, it can cause liver and kidney damage resulting in death. Moderate exposure to copper however is normal but there are certain circumstances where large levels of copper can enter humans, in some cases soluble copper can be found in drinking water due to copper pipes degrading or occasionally it can be due to algae treatment in fresh water lakes that use copper. There is also a very high risk of copper poisoning in the workplace, copper miners and copper workers will be spending their day mining and grinding copper metal which releases small copper dust particles which when it interacts with the skin can cause irritation and can also enter through the respiratory system. These risks though can be very high it is often not a large worry as most cases of copper poisoning are minor and often excess copper will leave the body through human waste within a few days. The amount of copper in the body tends to stay constant as the body will intake copper from sources such as food and other natural sources at a very moderate level to maintain necessary copper levels and then flush out any excess.

Copper is a naturally occurring element that is found and is most commonly mined through a process called open pit mining. Copper naturally has a reddish-brown color and is found throughout the globe, it appears nearly universally in cultures around the world. The main producer by a landslide is Chile which “produces 5,750,000 tons of copper annually”, China is second with “1,760,000 tonnes per year” while Peru is a close third with “1,380,000 tonnes per year” (Pariona, 2017). Copper is most present in the earth’s crust and is extracted through two methods, underground mining where shafts are drilled down and then miners will dig horizontally below the surface or open pit mining where the copper is found near the surface and it is simply quarried out. Copper is not always found as native copper though and is often found as compounds of different elements, the most common being Chalcopyrite or CuFeS2. To purify and retrieve the raw copper, the metal must go through an intense extraction process. The ore starts by being crushed and ground into tiny particles, the ground particles are placed into a vat of chemicals and water which have the properties so the Chalcopyrite floats to the surface while the waste rock is left at the bottom. The Chalcopyrite then goes through a series of furnaces where the iron and sulfur are removed from the Chalcopyrite to form pure copper, the iron and sulfur by-products are then harvested for other applications such as sulfuric acid or iron metal. The pure copper is not useful for some applications, so it will then be refined, and the properties will be adjusted so that they match the application for example, improving conductivity or corrosion resistance.

## Calculations

### 1. Write the balanced chemical equation for the reaction.

Copper(ii) sulfate pentahydrate + iron wool + water → copper metal + iron(iii) sulfate pentahydrate + water

CuSO4  ●5H2O(s) + Fe(s) + H2O→ Cu(s) + Fe2(SO4)3 ●5H2O  (aq) + H2O

3CuSO4 ●5H2O (s) + 2Fe(s) + H2O(aq) → 3Cu(s) + Fe2(SO4)3●5H2O  (aq) + H2O(aq)

     3  : 2        : 3 :     1

### 2. What mass of Cu(s) can be prepared by the reaction of iron wool

3CuSO4 : 3Cu

2g  / (63.55 + 32.66 + 4 \* 16.00 + 5 \* 18.02)g/mol = 0.008mol CuSO4  ●5H2O(s)

1 : 1

0.008mol CuSO4  ●5H2O(s) : 0.008mol Cu

0.008mol Cu = m/63.55

0.008mol\*63.55= m

m=0.508g of Cu

Estimated percentage yield ~95%

0.508g \* 95% = 0.483g

∴ The goal is to synthesize 0.483g of Cu (s) to have an expected yield of 95%

# Materials List

|  |  |
| --- | --- |
| Amount | Materials List |
| 1 | Safety goggles |
| 1 | Stirring rod |
| 2 | 250 ml beaker |
| 100ml | Distilled water |
| 2g | copper(ii) sulfate pentahydrate |
| 0.46g | Iron wool |
| 1 | Sheet of filter paper |
| 1 | Sheet of paper towel |
| 1 | Funnel |
| 1 | Metric scale |
| 1 | Crucible tongs |

# Procedure:

1. Gather materials
2. Put on safety goggles
3. Pour 100ml of distilled water into the beaker
4. Pour 2g of copper(ii) sulfate pentahydrate into the test tube
5. Using the crucible tongs place 0.46g of iron wool in the solution of copper(ii) sulfate
6. Stir the solution for approximately 5 minutes or until the iron wool appears to be broken up
7. Measure the mass of the filter paper
8. Form the filter paper into a funnel shape
9. Place the filter paper into the funnel
10. Place the funnel over the second beaker
11. Slowly pour the solution from the beaker into the funnel
12. Wait while the solution filters through the paper
13. Remove the filter paper from the funnel and place on a sheet of paper towel
14. Record Observations of the remaining liquid solution
15. Record Observations of the substance left on the filter paper
16. Dispose of liquid solution
17. Let the filter paper dry for 1 day
18. Record the mass of the substance
19. Dispose of Remaining Materials

# Hypothesis and Rationale

If 0.46g of iron wool is reacted with 2g of copper(ii) sulfate pentahydrate in 100ml of distilled water and the percentage yield is 95% then 0.48g of iron(iii) sulfate pentahydrate will be produced. This will happen due to the chemical formula that can be derived from this reaction where there is a 1:1 mole ratio between copper(ii) sulfate pentahydrate and copper. In this reaction the iron will displace the copper in the copper(ii) sulfate pentahydrate creating iron(iii) sulfate pentahydrate and the copper metal. The 95% percentage yield can be derived from previous similar experiments which got percentages yields of between 90 to 95%. This 95% percentage yield is not 100% due to many factors including human error as well as the impossibility to get completely accurate measurements. This hypothesis will be correct if there is no contamination of materials and an accurate amount of each reactant is utilized.

# Experimental Results

|  |  |  |
| --- | --- | --- |
| **Fe** | **CuSO4 (Limiting Reactant)** | **Cu** |
| 0.5g | 1.5g | 0.5g |
| 1g | 2g | 0.7g |
| 1.5g | 1.5g | 0.7g |
| 0.5g | 1.5g | 0.6g |
| 0.46g | 2g | 0.6g |
| 0.46g | 2g | 0.59g |
| 1g | 2g | 0.43g |
| 0.8g | 2g | 0.9g |

Table 1. Mass of limiting reactant (g) vs. Mass of Cu (g)

|  |  |  |
| --- | --- | --- |
| **Fe** | **CuSO4 (Limiting Reactant)** | **Cu** |
| 0.009mol | 0.006mol | 0.008mol |
| 0.018mol | 0.008mol | 0.011mol |
| 0.027mol | 0.006mol | 0.011mol |
| 0.009mol | 0.006mol | 0.009mol |
| 0.008mol | 0.008mol | 0.009mol |
| 0.008mol | 0.008mol | 0.009mol |
| 0.018mol | 0.008mol | 0.007mol |
| 0.014mol | 0.008mol | 0.014mol |

Table 2. Moles of limiting reactant (mol) vs. Moles of Cu (mol)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **H2O** | **Fe** | **CuSO4 ●5H2O** | **Solid Product** | **Liquid Product** |
| Clear Liquid | Lustrous, silver coloured, made up of thin strands of wire, wrapped into a small ball. | Small lustrous solid blue crystals. When mixed with water the water gains a blue tint. | Brown hard coating, underneath there is a brown, copper colored coating around the wools strands, some still silver. | Translucent liquid remains, slight green tint. |

Table 3. Qualitative observations of the reaction between Fe and CuSO4●5H2O

Figure 1. Moles of limiting reactant vs Moles of Cu

Figure 2. Moles of limiting reactant vs Moles of Cu average with extrapolation

Figure 1. and Figure 2. represent the number of moles of the limiting reactant compared to the resulting product of Copper. This data can be then extrapolated to represent how this reaction can be scaled for potentially industrial or commercial applications. This also represents how the reaction scales linearly meaning that the ratio between the number of reactants compared to the products will be the same no matter the number of moles of the limiting reactant.

# Discussion

The hypothesis was ultimately proven to be incorrect due to some inherent failures in the procedure and calculations of the lab. For future experiments the procedure must be improved and altered as the expected result was not met. Better calculations also must be done as the calculations were incorrect, certain factors were not considered such as purity, percentage efficiency, and side reactions. Though the hypothesis was not correct, the lab itself did fulfill its purpose and taught some important chemistry concepts that may have not been fully taught if the hypothesis was actually found to be correct.

Through this experiment it was discovered that though the basic stoichiometry equations are very effective, there are also many variables which must be considered when preparing for a lab. When performing a lab, the percentage yield must be considered, the reactions are nearly never going to be 100% efficient so the experimenter must discover what the efficiency of the reaction was and figure out how to correct the experiment to resolve these issues. Experimenters must also conduct studies on the purity of their materials, the stochiometric equations will only be effective if all the materials are 100% pure but this is nearly never the case, regular copper tends to be approximately 98% pure as it has imperfections, these variables must be accounted for when conducting a lab and writing a procedure. In this particular lab when calculating the mass of the products they did not directly correlate with the experimental results, there was a greater mass of products then was expected.

This lab also represented the importance of limiting and excess reactants as well as accounting for these when producing a reaction. In this reaction through the observations it was discovered that since the limiting reactant was copper(ii) sulfate, there was no copper(ii) sulfate in excess after the reaction though there were signs of iron wool strands representing how during a reaction the limiting reactant is always used to completion while the excess reactant will have some remaining. If iron were the limiting reactant then there would be an excess of copper(ii) sulfate found in the liquid solution creating a blue tint while there would be no iron wool strand in excess. The copper(ii) sulfate was chosen as the limiting reactant as it would mean that the maximum amount of copper would be displaced to create the copper strands to fully represent the reaction while having iron as a limiting reactant would result in very small amounts of copper being displaced. There was also a very interesting result found, for all the attempts at the experiment, the mass of copper was always greater then the mass of the limiting reactant. This defies the concepts of stoichiometry as in the original equation copper(ii) sulfate had a one to one molar relationship however the results showed that more copper was produced then was expected. The ideal graph would show a linear relationship between moles of product and limiting reactant with an equation of y=x as the moles of the limiting reactant should increase at the same rate as the moles of copper.

# Sources of Error

The experimental yield of copper was 0.59g while the expected yield was 0.483g, this gives a 122% percentage yield. More product was produced then expected this can be explained with a combination of multiple factors. There may be an issue in the procedure, the procedure may be in an incorrect order causing the reaction to be performed in an incorrect way. There may be a side reaction, the reactants may be reacting with other compounds which create different by-products, or the products may be reacting to create even more products which would create a greater solid mass. Finally, there may be an issue with contamination and improper equipment that could lead to other elements increasing the mass of our products.

One source of potential error is an error in the procedure. It was assumed during the production of the procedure that all the iron (iii) sulfate and product that was not copper would filter through the filter paper and the funnel. However, it was found that there was a hard, brown coating around the copper wire. This brown coating was not copper and thus when it was weighted the mass measured was not the mass of the copper but the mass of the total solid products. The procedure should be changed so as to remove the actual copper wire from the total product. The procedure should be modified so that the performer of the experiment will crush the hard, brown coating and individually remove the copper wire, potentially with a magnet. This is most likely the major cause of the error because having another substance on the scale, would directly affect the measured mass.

Another possible source of error is contamination. There are many different potential sources of contamination and they may combine to create a large difference in the measured mass. Oxidation could be a large part of the contamination. When iron reacts with oxygen it oxidizes to form iron oxide or rust, copper can also be oxidized and when it reacts with oxygen it forms a green coating. Both these reactions could cause the measured mass to increase as the actual mass of the iron wool would increase outside of the reaction and the mass of the copper would increase while its drying. These could have a potential to create a change in the mass of the substances however this is highly unlikely. The mass changed by oxidization would be extremely minute as rust adds little mass. There would have been some indication of contamination or oxidization, the copper wire would appear green, the iron would appear reddish brown. Oxidization also happens over a large timescale, the one day the copper wire spent drying would cause little oxidization and the iron wool was left outside of the container for less then 1 hour. To prevent this the lab should be done in a more ideal condition, with a cleaner lab and ideally the iron would be put taken directly from the container and immediately placed in the solution while the copper would be placed in a sealed container as well immediately after reaction.

One final potential source of error is multiple reactions taking place. It had not been tested whether any of the products react with the reactants. One major flaw in some reactions is that while the reaction is taking place one of the reactants may react with the products to create another separate product. It is rare but the iron(iii) sulfate could have reacted with either of the reactants to create another separate solid product. This would explain the hard, brown coating as it would be a by-product of a separate reaction occurring. This could be fixed by testing the different reactions that take place when both the reactants are tested against the iron(iii) sulfate to test if they react and adjust the procedure to prevent these two substances from reacting.

# Conclusion

When 0.46g of iron wool was mixed with 2g of copper(ii) sulfate pentahydrate 0.59g of copper was produced. This disproved the hypothesis that this reaction would produce 0.483g of copper product. Though ultimately the hypothesis was discovered to be incorrect it did shed light on some very important chemistry concepts and methods. This lab demonstrates the importance of stoichiometry but also represents its limitations and shows the experimenter how to better account for certain variables despite their apparent insignificance. The lab represents the importance of limiting reactants and the effects that it can have on an outcome and how miniscule changes in the mass of the reactants can change the overall result for the products. For the future experiments the procedures and calculations must be tweaked to account for these inconsistencies including better estimations on percentage yield as well as better tests for purity and preventing contamination. Though the hypothesis was disproven, the failure of the hypothesis describes a lot about how the theoretical world interacts with the practical world and demonstrates the abilities of stochiometric equations.

# References

Agency for Toxic Substances & Disease Registry. (2004, September). *Public Health Statement for Copper.* Retrieved from Agency for Toxic Substances & Disease Registry: https://www.atsdr.cdc.gov/phs/phs.asp?id=204&tid=37

Calcutt, V. (2001, August). *Introduction to Copper: Mining & Extraction.* Retrieved from Copper Development Association Inc.: https://www.copper.org/publications/newsletters/innovations/2001/08/intro\_mae.html

Pariona, A. (2017, April 25). *Top Copper Producing Countries In The World.* Retrieved from World Atlas: https://www.worldatlas.com/articles/top-copper-producing-countries-in-the-world.html

United States Geological Survey. (2009). *Copper—A Metal for the Ages.* Retrieved from U.S. Geological Survey: https://pubs.usgs.gov/fs/2009/3031/FS2009-3031.pdf