AP Chemistry Lab: Percent Yield of Paint Pigments

Background

All paints contain pigment, which provides color, and a binder (or medium), which suspends the pigments and binds them to the surface of the object to be painted. Two paint pigments, malachite and verdigris, are synthesized in this general chemistry laboratory experiment and then a tempera paint is made using malachite. Copper sulfate is the starting material for the one-step synthesis of malachite and the three-step synthesis of verdigris. Malachite pigment is combined with egg yolk binder to make tempera paint.

Greenish malachite, copper(II) carbonate hydroxide, $CuCO_3Cu(OH)_2$, occurs with copper ore deposits in many parts of the world. Malachite is a secondary mineral, created by a chemical reaction with minerals that have already formed, for instance, by the action of water containing carbon dioxide or dissolved carbonate minerals on primary copper-containing rocks. Verdigris ("green of Greece") can be collected by scraping the colored crust from sheets of copper exposed to vapors from vinegar, wine, or urine with the addition of other substances such as NaCl, ammonium salts, and honey. If a copper penny (pre-1982) is placed in vinegar, a green solution of copper acetate is visible after a few weeks. However, the verdigris produced using methods similar to this can lead to a mixture of chemical compositions and different colors, particle sizes, and morphologies. The synthetic methods described here for both copper containing pigments start with copper sulfate and use readily available materials and simple techniques. Methods used to prepare other pigments, including chrome yellow, $PbCrO_4$, Prussian blue, thalo blue, iron(III) oxide, titanium dioxide, and charcoal have appeared in the Journal of Chemical Education.

Paints are generally named from the binder used. Oil paint is made with linseed oil, egg tempera with egg yolk, and acrylic paint with acrylic polymers. Watercolor, however, is named for water, the diluent added to make the paint spreadable, rather than the binder, which is gum arabic or some other gum or starch. Although any pigment can be used with any binder, in some cases a particular binder may produce superior paint. For example, malachite gives brighter colors with egg tempera than with oil. In the second part of this laboratory exercise, the synthetic malachite pigment is dried, ground to remove lumps, then mixed with egg yolk/water emulsion to make egg tempera paint.

Purpose

In this experiment, the principles of stoichiometry will be applied to produce two paint pigments through a series of chemical reactions. Based on the chemical equations and the quantities of reactants used, the limiting reactant and theoretical yield will be determined. The actual yield measured in the lab will then be used to find the percent yield for each pigment isolated.

Safety

You are required to research the SDS (Safety Data Sheets) of each material used in the experiment and record information regarding hazards the materials have to humans and the environment. You should also explain any procedures that have inherent safety considerations (e.g. precautions with lab burners, etc.) as described in the Flinn Safety contract.

Materials

copper (II) sulfate pentahydrate	sodium carbonate	glacial acetic acid (vinegar, $HC_2H_3O_2$)
ammonia (NH_3)	sodium hydroxide	linseed oil
egg yolk	beakers	magnetic stirrer
graduated cylinders	scoopula	evaporating dish
stirring rod	pipettes	filter paper
ring stand	hot plate	vacuum flask and Buchner funnel

Procedure

Part 1: Synthesis of Malachite

1. Mass 1.00 gram of copper (II) sulfate pentahydrate.
2. Add to a 150 mL beaker and dissolve in 15 mL of distilled water with vigorous stirring.
3. Mass 0.80 grams of sodium carbonate.
4. Dissolve in 15 mL of distilled water in a separate clean beaker.
5. Slowly add the sodium carbonate solution to the copper solution.
6. Cool in an ice bath for 10 minutes. (During this time, move on to the *Synthesis of Verdigris*)
7. Label and weigh a piece of filter paper. Filter the solution using the vacuum filtration set up as demonstrated in class.
8. Gently heat the product to dryness in the drying oven.
9. Obtain the product mass.
10. Separate an egg yolk from the egg white.
11. Add a small amount of egg yolk to the dry product in a Dixie cup. Thoroughly mix with a Q tip until all lumps are removed (you may need to add some water to achieve proper consistency) and paint a pretty picture.

Part 2: Synthesis of Verdigris

1. Mass 2.00 grams of copper (II) sulfate pentahydrate.
2. Dissolve in 15.0 mL of distilled water with vigorous stirring.
3. Add ammonia (under fume hood) DROPWISE until the dark blue color just persists throughout the entire mixture. Stir the mixture thoroughly.
4. In a separate beaker, dissolve 0.40 grams of sodium hydroxide in 10.0 mL of distilled water.
5. While stirring, add sodium hydroxide to the product mixture.
6. Label and weigh a piece of filter paper. Filter the solution using the vacuum filtration set up as demonstrated in class.
7. Scrape the solid product from the filter paper and add to a pre-weighed evaporating dish.
8. Slowly add glacial acetic acid dropwise under the fume hood until the solid is fully covered and stir.
9. Place on a designated hot plate in a fume hood and cover with a watch glass. Heat until the liquid has completely boiled off and a solid residue remains.
10. Weigh the evaporating dish with the product and record your results. Scrape the solid into a Dixie cup.
11. Add linseed oil dropwise and mix with Q tip until it reaches the proper consistency and paint a pretty picture.

Data Tables

Include all qualitative data (observations) and quantitative data (measurements) in data tables. Remember to include all numbers that were measured in the lab and all numbers calculated in the quantitative data table.

Reaction Equations

Synthesis of Malachite ***(balance the equation below)***

___ $CuSO_4 \cdot 5H_2O_{(aq)}$ + ___ $Na_2CO_{3\,(aq)}$ → ___ $CuCO_3Cu(OH)_{2\,(s)}$ + ___ $Na_2SO_{4\,(aq)}$ + ___ $CO_{2\,(g)}$ + ___ $H_2O_{(l)}$

Synthesis of Verdigris

4 $CuSO_4 \cdot 5H_2O_{(aq)}$ + 6 $NH_{3\,(aq)}$ → 1 $CuSO_4 \cdot 3Cu(OH)_{2\,(s)}$ + 3 $(NH_4)_2SO_{4\,(aq)}$ + 14 $H_2O_{(l)}$

1 $CuSO_4 \cdot 3Cu(OH)_{2\,(s)}$ + 2 $NaOH_{(aq)}$ →4 $Cu(OH)_{2\,(s)}$ + 1 $Na_2SO_{4\,(aq)}$

1 $Cu(OH)_{2\,(s)}$ + 2 $HC_2H_3O_{2\,(aq)}$ → 1 $Cu(C_2H_3O_2)_2 \cdot H_2O_{(aq)}$ + 1 $H_2O_{(l)}$

Post-Lab Calculations **(annotate and show all work with units as explained in class)**

Synthesis of Malachite

1. Determine the limiting reactant in this reaction. Use calculations to support your claim.
2. Calculate the grams of excess reactant that would be unconsumed at the completion of the reaction.
3. Using laboratory data, determine the experimental yield for malachite.
4. Using stoichiometry, determine the theoretical yield of malachite.
5. Determine the percent yield for this reaction.

Synthesis of Verdigris

1. Using the amount of copper (II) sulfate pentahydrate that was used experimentally, determine the mass of precipitate formed theoretically in the first reaction.
2. Use your result of calculation 1 to determine the mass of precipitate theoretically formed in the second reaction.
3. Use your result of calculation 2 to determine the mass of verdigris produced theoretically.
4. Use your data to find the experimental (actual) yield of verdigris.
5. Determine the percent yield of verdigris.

Conclusion Questions

1. Explain why the percent yield of malachite was higher than that of the verdigris. Use the procedures and your observations during the experiment to support your explanation.

2. If the water had not all been evaporated from the malachite in procedure 1, how would your percent yield have been affected? Explain step by step, in terms of cause and effect of the error on the results.