

The Determination of a Chemical Formula

John Dalton was an Englishman, a teacher, and an exceptional theoretical chemist. He developed and wrote the modern atomic theory at the turn of the 19th century (documents point to 1803). He was influenced by the experiments of two Frenchmen, Antoine Lavoisier and Joseph Louis Proust. A fundamental component of the modern atomic theory is that the mole ratios of elements in a compound will be small whole numbers (*law of definite proportions*). The whole number mole ratio is commonly referred to as the empirical formula of a compound.

One of the challenges in finding the proper chemical formula for a compound is that there may be more than one plausible mole ratio for the elements in that compound. Dalton called this the *law of multiple proportions*. For example, if you were testing a compound that contained iron and sulfur, the plausible chemical formula could be FeS or Fe₂S₃. However, if you determine the mass of iron and the mass of sulfur present in a given mass of the compound, you will be able to establish the true chemical formula of the compound.

In this experiment, you will use the law of definite proportions to find the chemical formula for a hydrated compound containing copper, chlorine, and water molecules locked in the crystal structure of the solid compound. The general formula for the compound is Cu_xCl_y·zH₂O, and its name is copper chloride hydrate. The letters x, y, and z represent integers that will establish the proper chemical formula for this substance. First, you will gently heat a sample of the compound to drive off the water of hydration. By measuring the mass of the sample before and after heating you can determine the amount of water in the sample and identify the value of z.

Second, you will conduct a chemical reaction with the dried sample, which will produce elemental copper. By measuring the mass of copper that forms, you will have the necessary information to determine the moles of copper and chlorine in your sample, and you will be able to establish the proper chemical formula.

OBJECTIVES

In this experiment, you will

- Determine the water of hydration in a copper chloride hydrate sample.
- Conduct a reaction between a solution of copper chloride and solid aluminum.
- Use the results of the reaction to determine the mass and moles of Cu and Cl in the reaction.
- Calculate the empirical formula of the copper chloride compound.

MATERIALS

crucible with cover	unknown solid copper chloride hydrate
crucible tongs	aluminum wire, 20 gauge
spatula	6 M hydrochloric acid, HCl, solution
ring stand, ring, and clay triangle	95% ethanol solution
lab burner	distilled water
50 mL beaker	wash bottle
Büchner funnel and filter flask	balance
filter paper to fit Büchner funnel	glass stirring rod
watch glass	heat lamp or drying oven

PROCEDURE

1. Obtain and wear goggles.
2. Measure and record the mass of a clean, dry crucible without cover. Obtain about 1 g of the unknown copper chloride hydrate and place it in the crucible. Use a spatula to break up any large pieces of the substance by pressing the pieces against the wall of the crucible. Measure and record the mass of the crucible with compound.
3. Set up a ring stand, ring, and clay triangle for heating the sample. Rest the crucible on the clay triangle. Set up a lab burner and ignite the burner away from the crucible. Adjust the burner to get a small flame.
4. Hold the burner in your hand and move the flame slowly back and forth underneath the crucible to gently heat the sample. Do not overheat the compound. Note the color change, from blue-green to brownish, as the water of hydration is driven out of the crystals. When the sample has turned brown, gently heat the crucible for two more minutes.
5. Remove and turn off the burner. Cover the crucible and allow the sample to cool for about ten minutes.
6. Remove the crucible cover and inspect your sample. If you see any blue-green crystals, reheat the sample until the crystals have turned brown.
7. Measure and record the mass of the cool crucible of your copper chloride sample.
8. Transfer the brown solid to a clean and empty 50 mL beaker. Rinse out the crucible with two 8 mL aliquots of distilled water and pour the water into the 50 mL beaker. Gently swirl the beaker to completely dissolve the solid. Note that the color of the solution is green as the copper ions are rehydrated.
9. Measure out about 20 cm of aluminum wire, coil the wire, and place the wire in the beaker of solution so that it is completely immersed in the copper chloride solution. Note that the reaction produces a gas, elemental copper is forming on the surface of the aluminum wire, and the color of the solution is fading. The reaction will take about 30 minutes to complete.

10. When the reaction is done, the solution will be colorless. Most of the elemental copper will be on the aluminum wire. Add 5 drops of 6 M HCl solution to dissolve any insoluble aluminum salts in the mixture, which should make the solution clear. **CAUTION:** Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin.
11. Use a glass stirring rod to scrape off as much copper as possible from the Al wire. Slide the wire up the wall of the beaker and out of the solution with the glass stirrer and rinse off any remaining copper with distilled water. If any of the copper refuses to wash off the aluminum wire, wash it with one or two drops of 6 M HCl solution. Put the Al wire aside.
12. Collect and wash the copper produced in the reaction.
 - a. Set up a Büchner funnel for vacuum filtration.
 - b. Obtain a piece of filter paper. Measure and record its mass, and then place the filter paper on the funnel. Start the vacuum filtration.
 - c. Use small amounts of distilled water to wash all of the copper onto the filter paper on the Büchner funnel. Use the glass stirring rod to break up the larger pieces of copper.
 - d. Wash the copper twice more with small amounts of distilled water.
13. Turn off the suction on the vacuum filtration apparatus. Add 10 mL of 95% ethanol to the copper on the filter paper and let it sit for about 1 minute. Turn the suction back on and let the vacuum filtration run for about five minutes.
14. Measure and record the mass of a clean, dry watch glass. Transfer the copper to the watch glass. Make sure that you have scraped *all* of the copper onto the watch glass.
15. Dry the watch glass of copper under a heat lamp or in a drying oven for five minutes. When the watch glass is cool enough to touch, measure the mass of the watch glass plus copper. Repeat the drying and weighing of the copper until you are sure that it is completely dry.
16. Dispose of the copper, aluminum wire, and filtered liquid as directed.

DATA TABLE

Mass of crucible (g)	
Mass of crucible and hydrated sample (g)	
Mass of hydrated sample (g)	
Mass of crucible and dehydrated sample (g)	
Mass of dehydrated sample (g)	
Mass of water evolved (g)	
Mass of empty watch glass (g)	
Mass of watch glass and copper (g)	

Mass of copper (g)	
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DATA ANALYSIS

1. How many moles of water were in your sample of copper chloride hydrate?

2. How many moles of copper were in your sample of copper chloride?

3. How many moles of chlorine were in your sample of copper chloride?

4. Write the proper chemical formula for the compound that you tested.