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Determining the Composition of a Brass Alloy Using Destructive and Non-Destructive Tests

Abstract:

This experiment entails calculating the mass composition of zinc and copper in a given brass sample through non-destructive and chemical analysis. Zinc and copper differ as metals in terms of their density, conductivity properties, relative reactivity in terms of an activity series, as well as in their relative heat capacity. Using the known physical properties of zinc and copper the composition of the brass will be calculated. The density of the brass sample will be determined by taking its volume and mass. A heated sample of the brass will then be placed into a calorimeter and the temperature change will allow us to calculate the specific heat capacity of the brass. Conductivity of the alloy will be measured with a multimeter by using the distance between the contact points and the resistance. Then, using an experimental graph, we will estimate the percent zinc content of the sample based on the percent International Annealed Copper Standard (IACS) conductivity of the alloy. We will also react a given mass of the sample with an iron salt to perform a single displacement reaction between the more-reactive zinc and the less reactive iron salt. A similar analysis will take place with a reaction between hydrochloric acid and zinc, leaving copper behind as a solid to analyze. Through several trials of these methods, it is possible to determine an accurate percent composition of a given brass alloy.

Introduction:

Brass, a binary alloy, consists of copper and zinc, with varying concentrations of zinc, usually ranging from about 5% to 40%.(3) The density of brass ranges from 8.3-8.7 g/cm^3, and the melting point from 1652-1724 °F (900-940 °C). Brass is stronger and harder than copper, but not as strong or hard as steel. It is resistant to salt water and corrosion. Different alloys of brass have different chemical and physical properties, such as color, hardness, ductility, electrical and thermal conductivity, machinability (the ease with which a metal can be formed into a shape while maintaining strength), and corrosion resistance. All brasses are considered ductile and malleable and have good electrical and thermal conductivity (electrical conductivity between 23% to 44% of pure copper).(2)

The composition of brass and other alloys can be found through several methods, as represented in this lab. The composition of brass will be found by conductivity, specific heat capacity, density, single displacement, and copper dissolution.

A metals conductivity is related to its charge carrier density (how many electrons are free to move about the metal and flow in response to an electric field) and carrier mobility (how freely the charge carriers can flow through the metal). A metal with high charge carrier density and mobility is highly conductive. The chemistry (specific properties of atoms) and structure (ie. crystalline) of the material affects the charge carrier density and mobility. The conductivity of copper is 5.96×10^7 S/m (siemen/meter), while the conductivity of zinc is lower at 1.7×10^7 S/m.(3) Thus, brass with a higher percentage of copper will be more conductive. By measuring the resistance of a metal using a multimeter, you can calculate the conductivity of the metal using conductivity = 1/(resistance*length), equivalent to a siemen.(9)

The specific heat capacity (c) of a metal is the amount of heat energy (Joules) required to raise one gram of a substance one temperature unit (Kelvin). The units of specific heat capacity are J/g K. The specific heat capacities of copper (0.386 J/g K) and zinc (0.387 J/g K) are very similar. Metals have lower specific heat capacities (less energy needed) than nonmetals. This is because the atoms in metals are tightly packed together and are able to easily transfer heat from one atom exciting the neighboring atoms.(8) The specific heat capacity of brass can be used to calculate its composition by using the specific heats of copper and zinc and setting up a system of equations as shown: $(5.96\times10^7$ S/m$)x+(1.7\times10^7$ S/m$)y=$experimental specific heat capacity of brass $\rightarrow x+y=1$, where x=% copper and y=% zinc. The composition of brass can be calculated similarly by finding the density of the brass and using the researched densities of copper and zinc.

A single displacement reaction is a type of chemical reaction in which an element reacts with a compound and takes the place of one of the elements in the compound. The element being replaced in the compound can only be replaced if the element taking its place is higher on the activity series. In single-displacement reactions a metal replaces a metal.(6) The activity series is referred to in order to determine which elements can replace each other (high reactivity correlates to the top of the series). As illustrated in Figure 1, copper is less reactive than zinc.(5) The composition of brass can be calculated by performing a redox single displacement reaction between brass and a Fe^{2+} solution. Because zinc is more reactive than iron, and because the iron is in solution, the zinc would ionize and place itself into the solution giving its electrons to the ionized iron which precipitates out as solid iron metal. The chemical formula for the reaction is as follows: $Zn_{(s)} + Fe^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Fe_{(s)}$. Similarly, this can be accounted for in other metals and cations, namely in acids, which produce H^+. Since copper is lower on the activity series, it is less reactive than hydrogen, meaning, when combined with most acids, copper and the other metals below hydrogen on the activity series, will not react with said acid. Zinc, however, is more reactive than hydrogen, which will cause it to undergo the following reaction: $2H^+_{(aq)} + Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + H_{2\,(g)}$. Since only the zinc reacts, only copper will be left behind as a solid when brass is reacted with HCl.

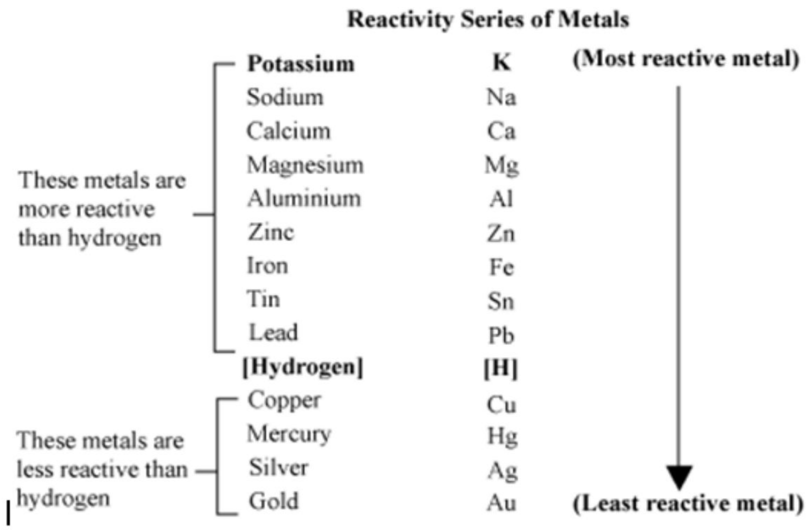

Figure 1: Reactivity series of metals. This show series of metals from most reactive to least reactive in the relation of hydrogen. Due to zinc being higher than hydrogen and copper below hydrogen it is possible to use an acid reaction to determine the composition of the brass. [5]

Justification:

The measure of physical properties is the focus of the first part of our protocol. We first measure the density, which requires both mass and volume to calculate. Calculating mass with a scale is the most reasonable option and is thus what we chose. When measuring volume, since we are unaware of the shape of our brass sample, the water displacement method will be the most consistent and accurate in measuring the volume of the sample. A high accuracy graduated cylinder will report consistent and accurate data regardless of the shape of the sample. It is important to mass the sample prior to measuring the volume, since excess water from the displacement measurement could affect the mass recorded.

The measurement of conductivity is our most error-prone and least precise method to determine the composition for a multitude of reasons. Conductivity is a defining trait in many metals, especially one which contains copper, the defining standard of the International Annealed Copper Standard for conductivity[3]. This methodology was designed with the components of the conductivity equation in mind: $1/(\Omega*m)$, or the inverse of the product of the resistance and length of the path between the contacts. Thus, using a multimeter, we are able to measure the resistance, and a simple ruler is enough to calculate the length in meters to calculate the conductivity. The reason this method is not reliable is due to the analysis methods, which depends on experimental graph-based data, rather than a numerical equation. This will further discussed in data analysis.

The methodology behind the specific heat capacity measurement follows the age-old chemistry equation where hot metal is dipped into cold water. The inspiration from there translates directly to the procedure: heating the metal sample provides it the heat to dissipate into the calorimeter. By measuring the initial temperature of both the calorimeter and the metal, and then the final temperatures, we can calculate the missing component of the equation: the specific heat capacity of the brass.

Both the Fe^{2+} salt and HCl utilize the activity series and how reactive different metals are relative to each other. Both the Fe^{2+} ion and H^+ ion are more reactive than the copper, meaning they will not displace it in a reaction. However, they are less reactive than the zinc in the brass, so they will displace with the solid zinc metal in the brass in a redox reaction. This will leave behind solid Fe metal, which will be extracted via a magnet. The product of the displacement between the zinc and hydrochloric acid is H_2 gas, meaning the only solid left is copper. Since copper is the only solid left in both scenarios, measuring the mass of the solid left will be equal to the proportion of copper in the brass alloy.

Materials:
- Lab balances
- Hot plate
- Magnets
- Digital thermometers
- Assorted glassware:
  - 2 250 mL beakers
  - 3 125 mL Erlenmeyer flasks
  - 1 10 mL graduated cylinder
- Thermos calorimeters
- Multimeter
- A Brass alloy
- 2 M HCl
- .1 M Fe^{2+} salt solution

Protocol

Density procedure:
1. Mass the sample of brass
2. Obtain a graduated cylinder that can fit the sample of brass inside it
3. Fill the graduated cylinder to a given volume with water and record it
4. Place sample of brass inside and record final volume to calculate the volume of the brass sample
5. Calculate brass sample density
6. Calculate the molar mass of copper and zinc
7. Create a system of equations where the coefficients are the densities of zinc and copper respectively at room temperature and the variables are the fractional composition of the respective metal:

a. 7.140x+8.96y=experimental density
b. x+y=1

8. Repeat with different samples of brass (with the same composition) for repeat trials.

Conductivity procedure:

(5.8001×10^7 S/m) is defined to be 100% IACS at 20°C

1. Gently wash brass sample to ensure clean electrical contact surfaces
2. Place multimeter contacts on either end of the brass sample and measure the length between the contact points using a ruler
3. Switch the multimeter to resistance and measure the resistance between the two contact points
4. Calculate the sample's conductivity by taking the reciprocal of the product between the resistance (measured in ohms) and the distance between the contact points (measured in meters). ($1/(\Omega*m)$) Units should be in Siemens/meters. [(2)]
5. Divide the sample's conductivity by the copper standard (5.8001×10^7 S/m) and multiply by 100 to obtain the % conductivity relative to the International Annealed Copper Standard. [(2)]
6. Using Figure 3 below, estimate percent zinc in the brass based on the conductivity.

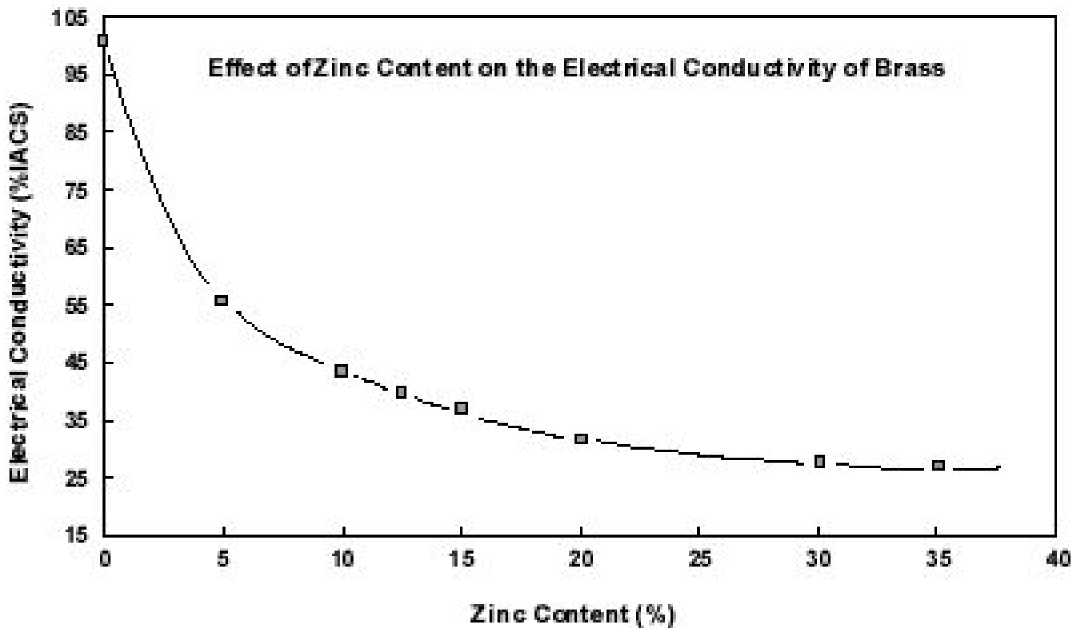

Figure 2: Zinc on Electrical Conductivity of Brass. This graph estimates the electrical conductivity of brass given a percent composition of zinc in the brass.[(1)]

Specific Heat Capacity Procedure:

1. Fill a beaker that will fit the brass sample with about 50 mL water and preheat water on hot plate
2. Mass sample of brass
3. Place brass into beaker with water and place thermometer in beaker

4. While heating brass sample, measure another 50 mL of water into a coffee cup calorimeter that will fit the entire brass sample in and record the temperature of the water
5. After about 3 minutes of heating, measure the temperature of the heated water with the brass sample inside. This will serve as the initial temperature of the brass sample
6. Place heated brass sample using tongs carefully into calorimeter with 50 mL water
7. Wait about 3 minutes, then swirl liquid in beaker gently and take temperature. This will be the final temperature of both samples

Single Displacement Procedure:

1. Mass an empty 125 mL erlenmeyer flask
2. Record the mass of an approximately 1 gram sample of brass (if the brass is in small pieces or powder form, this is preferable for the greater surface area) and add into a 125 mL erlenmeyer flask
3. Add excess (about 50 mL) Fe^{2+} solution **(need higher concentration than 1 mM in lab)** into erlenmeyer flask
4. Stir for about 15 minutes using stir bar
5. Decant solution off from flask, being careful not to lose any of the metal at the bottom
6. Pour distilled water into flask, swirl around multiple times, and decant water again. Perform this washing two more times times
7. Gently rub a magnet against the accumulated metal powder at the bottom to collect precipitated iron. Slowly drag up magnet along the walls of the flask to take the iron filings out of the flask. Repeat this multiple times until no iron filings are extracted from the metal clump
8. Place flask onto a hot plate at about 50 degrees Celsius
9. When contents of flask are dry, remove from heat and wait for it to cool. Mass flask with contents inside and use measured mass of flask to calculate mass of contents (copper metal)

Copper Dissolution Procedure:

1. Mass a 125 mL Erlenmeyer flask
2. Mass about .5 grams of brass wire and record exact mass
3. Combine brass wire with 5 mL of 2M HCl and stir until gas bubbles stop forming
4. Decant solution off, making sure to leave metal solids behind
5. Add 10 mL distilled water to the flask and swirl for 2 minutes
6. Decant water off, leaving metal behind in flask
7. Place flask on hot plate at no more than 50 degrees Celsius until all liquid has dried off
8. Mass the flask with the metal in it and subtract the mass of the flask to obtain the mass of the copper left behind

Safety Analysis

General Precautions:

- Wear appropriate eye (safety goggles/glasses) and skin (lab coats and pants) protection.
- Immediately wash eyes or skin if contacted.
- Remove clothing that becomes wet or significantly contaminated.
- Seek medical attention if eyes, skin, or nose are irritated, substance is swallowed, tears are discharged, headache is induced, chest tightens, skin burns, or rash appears.
- Immediately remove to fresh air, if feeling light-headed.
- Always handle materials with labeled containers.

Zinc, Granular: Safety Sheet[(4)]

- May cause eye and skin irritation.
- If inhaled, may cause respiratory and digestive tract irritation.
- Dispose of properly, as it may cause long-term adverse effects in the aquatic environment.

Hydrochloric Acid (HCl): Safety Sheet[(4)]

- May be corrosive to metals.
- Causes severe skin burns and eye damage.
- May cause respiratory irritation, if ingested.
- When heated, produces chlorine gas, which causes respiratory tract irritation.

Brass Alloy: Safety Sheet[(4)]

- Inhalation overexposure to copper or zinc oxide may cause metal fume fever characterized by fever and chills.
- High concentrations of dusts or fumes may cause irritation to the eyes. Inhalation of metal fumes or dusts generated during welding, burning, grinding or machining may cause irritations of the respiratory tract.

Ferrous Iron (Fe^{2+}): Safety Sheet[(7)]

- Overexposure may be irritating to eyes, skin, and respiratory tract and induce nausea.
- Avoid contact with oxidizers, phosphates, and heat.
- Fire or explosion may emit toxic fumes and acrid smoke.

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