

PERCENT COPPER IN BRASS (SPECTROMETER)

Brass is an alloy of various metals including copper, zinc, aluminum and tin. Copper, zinc and iron are typically the most abundant. The relative proportions of these metals greatly influence the properties and utility of brass. Such properties as color, hardness, ductility and conductivity change depending on the content of the various metals in the alloy.

Alloys are solid substances that are mixtures of two or more solid elements. They are classified as either substitutional or interstitial depending on the atomic arrangement that forms the alloy. The components of an alloy affect many of the physical properties of an alloy such as hardness or strength. Steel is an interstitial alloy that combines elemental iron with non-metallic carbon or silicon. It is considered an interstitial alloy because the very small carbon atoms fit into interstices of the iron matrix. The increase in hardness and tensile strength of steel makes it a much more attractive metal for use in construction compared to iron.

Brass, on the other hand, is a substitutional alloy that is a combination of copper and a number of other metals like zinc, aluminum, tin, lead or iron in varying quantities. In a substitutional alloy, the sizes of component atoms are comparable such that one can be substituted for the other. The percent copper content of any given brass alloy affects its mechanical strength, ductility, hardness, electrical conductivity and resistance to corrosion. For example, the ratio of copper to tin in brass dictates its uses ranging from musical instruments, construction, decorative elements and electrical switches. The table below shows a few of the 300 known formulations of brass and their common uses.

Type of Brass	% Cu	% Zn	Use and Other Information
High brass	65	35	Springs, rivets and screws
Low brass	80	20	Flexible metal hoses, high ductility
Manganese brass	70	29	“Gold” dollar coins in the U.S.
Naval brass	59	40	Marine construction; resists corrosion
Nordic gold	89.5	5	“Gold” Euro coins
Yellow brass	67	33	Decorative elements, saxophones, trombones

Spectroscopy is the study of the interaction of electromagnetic radiation and matter. Visible spectroscopy is a simple tool to determine the percent copper content in a sample of brass because the absorption of electromagnetic radiation causes different kinds of transitions within the substance. The energies of these transitions are characteristic of a specific atom or molecule. The concentration of a colored transition metal ion solution can also be determined by measuring the color intensity.

In this investigation, a brass sample is dissolved in nitric acid and only one colored species is produced in solution. The copper (II) ion has a blue color when in solution. The concentration of copper in the brass sample is measured by evaluating the intensity of the blue color of the solution. According to Beer's law, the absorbance of the colored solution is directly proportional to its concentration. This relationship is described by the equation $A = \epsilon lc$ where A is absorbance, ϵ is the molar absorptivity with units of $L \cdot mol^{-1} \cdot cm^{-1}$, l is the path length (in cm) of the cuvette which holds the sample, and c is the concentration of the compound in solution expressed in $mol \cdot L^{-1}$. Plotting absorbance versus known concentrations for a series of standard solutions will generate a linear calibration curve. The direct, linear absorbance-concentration relationship can be expressed in the form of the linear function $y = mx + b$ where y is the absorbance measurement from the spectrometer, x is the solution concentration and b is the y-intercept. The copper ion concentration (x) of the brass sample is then determined using this equation.

Objectives

The concepts covered in this lab align to the “AP[®]* Chemistry Course Framework.”

- **Learning Objective SAP-8.C:** Explain the amount of light absorbed by a solution of molecules or ions in relation to the concentration, path length and molar absorptivity.
- **Learning Objective SPQ-4.A:** Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.
- **Science Practices:** SP 5.D, 6.B, 6.A, 2.C, 5.A, 5.E
- **NGSS** DCI:** HS-PS1

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Materials and Equipment

Use the following materials to complete the initial investigation. For conducting an experiment of your own design, check with your teacher to see what materials and equipment are available.

- Data collection system
- Spectrometer
- Spectrometry software
- Cuvettes (11)
- Precision balance (readability: 0.001 g)
- Beaker, 150-mL
- Volumetric flask, 100-mL
- Graduated cylinders (3), 10-mL
- Glass stirring rod
- Watch glass
- Test tubes (8), 15-mL capacity or greater
- Test tube rack
- Disposable pipettes (2)
- 0.20 M Copper(II) nitrate ($\text{Cu}(\text{NO}_3)_2$)
- 15.6 M Concentrated nitric acid (HNO_3)
- 0.1 M Transition metal solutions: Copper(II) nitrate, copper(II) sulfate, iron(III) nitrate, iron(II) sulfate, zinc nitrate
- Brass samples (2), ~0.3 g to ~1 g each
- Lint-free lens wipes
- Wash bottle filled with distilled water

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles at all times. Wear gloves if available.
- Work in a fume hood or well-ventilated area. Concentrated nitric acid is severely corrosive and toxic by ingestion or inhalation; nitrogen dioxide is a toxic, reddish gas and is a by-product of this reaction.
- Wash hands thoroughly with soap and water before leaving the laboratory.
- Follow your instructor's disposal directions.

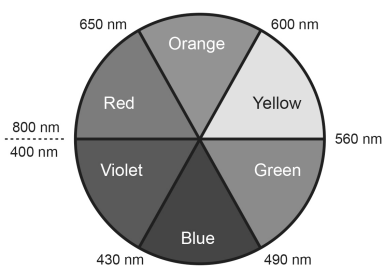
Pre-Lab Questions

- In this lab, you will be dissolving copper-containing brass in a concentrated oxidizing acid, nitric acid. A gas, nitrogen dioxide, is a by-product of the oxidative process that also produces aqueous copper(II) nitrate and liquid water. Write the complete balanced equation for this reaction.

- Write the complete ionic and net ionic equations for this reaction.

- If a 1.00 g sample of brass is 80% copper by mass, what is the minimum volume of 6.0 M nitric acid needed to react with the sample completely?

- Copper(II) ions are transmitted as the color blue in solution. Based on the color wheel and principle of complementary colors, which colors or wavelengths of light would you expect to be the most strongly absorbed by Cu^{2+} ions?



Initial Investigation

Visible Spectra of Transition Metal Ions

1. Connect the spectrometer to the data collection system.
2. Add distilled water to a cuvette to prepare a calibration blank.

NOTE: Fill cuvettes $\frac{3}{4}$ full. Do not overfill. Handle by the sides that are not clear. If bubbles are present, gently tap the cuvette to dislodge the bubbles.

3. Insert the cuvette into the spectrometer. Perform a dark and light calibration. Absorbance should read zero after calibration is complete.

NOTE: Wipe the clear sides of the cuvette with a lint-free lens wipe. Insert the cuvette with the clear sides in line with the light and spectrum icons on the device.

4. Your teacher will provide you with two samples of transition metal solutions. Transfer solutions to cuvettes.
5. Start recording data. Determine the optimum wavelength that demonstrates each sample's maximum absorbance *within the visible spectrum* (λ_{max}). Record the visible-spectrum λ_{max} for each solution. Report spectral data to the class for the advanced investigation activity.
6. Do Zn^{2+} ions absorb visible light? Discuss the answer in terms of the physical appearance of Zn^{2+} solutions and the electronic structure of Zn^{2+} ions.
7. If Fe^{3+} ions are present in your brass sample, do you expect them to interfere with Cu^{2+} analysis at its optimal wavelength? Explain your answer.

Calibration Curve for Copper(II) Ion Solutions

1. Prepare a series of dilutions of 0.20 M $\text{Cu}(\text{NO}_3)_2$ as specified in Table 1. Use the calibration blank as Solution 8. Calculate the final concentration of each sample and record your answers in Table 1.
2. In Spectrometry, display any previously recorded Cu^{2+} run. Move the coordinates tool to the λ_{max} identified in Step 5 of the previous activity. Click the check mark to accept and set the analysis wavelength. A black vertical line will appear through λ_{max} once you have successfully selected the analysis wavelength.
3. Choose the Concentration icon above the graph to show a table and graph display in Spectrometry.
4. Update the Concentration column in the table to match calculated concentrations for solutions 1-8 in Table 1.
5. Place Solution 1 in the spectrometer and start recording data.
6. Select the box for absorbance of the first solution in the Spectrometry table. Once the reading stabilizes, click the check mark to keep the absorbance value. Record the measured absorbance for Solution 1 in Table 1.
7. Record absorbance measurements for the remaining solutions in Table 1.

NOTE: Don't forget to click the check mark to keep the absorbance value for the last solution.

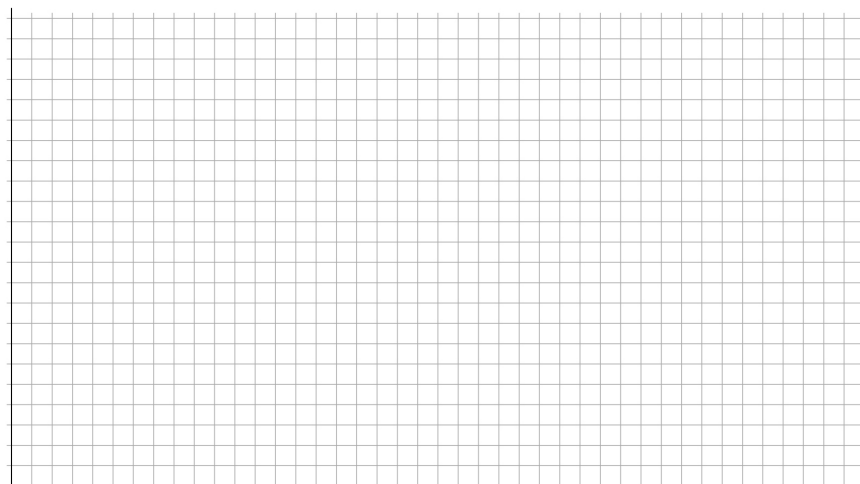
8. Stop recording data. Scale the graph. Select Absorbance on the y-axis to toggle the graph and table data to % Transmittance. Record transmittance values for all solutions in Table 1. Toggle the y-axis back to Absorbance when finished.
9. Add a linear fit to your graph. Record the linear fit data (no need to include \pm values) in the space provided in Table 1.

10. Sketch your calibration curve with linear fit in Graph 1. Include appropriate intervals, labels, and units for x- and y-axes. Save your data in Spectrometry.

Table 1. Cu^{2+} Ion Solution Data

Solution #	Volume of 0.20 M $\text{Cu}(\text{NO}_3)_2$ stock solution (mL)	Volume of distilled water (mL)	Dilute solution concentration (M)	Absorbance	% Transmittance
1	10.0	0			
2	8.0	2.0			
3	6.0	4.0			
4	4.0	6.0			
5	3.0	7.0			
6	2.0	8.0			
7	1.0	9.0			
8	0	10.0 (use the calibration blank)			
Linear fit values			Slope (m):	y-intercept (b):	Linearity (r):

Graph 1: Calibration Curve of Cu^{2+} Ions



Advanced Investigation

Percent Copper in Brass

1. Weigh out between 0.3 and 1.0 g brass to the nearest 0.001 g and record the exact mass.
2. Assume your sample is 100% copper. What volume of concentrated 15.6 M HNO_3 is needed for a complete reaction with the sample? Show your calculations.
3. In a chemical fume hood, transfer the brass sample to a 150-mL beaker and add the appropriate volume of concentrated 15.6 M HNO_3 . Cover with a watch glass and allow the reaction to proceed for 10-20 minutes or until your brass sample has dissolved.
4. Still working in the hood, add about 30 mL distilled water to the reaction mix in the beaker. Gently stir the solution and remove it from the hood.
5. Transfer the solution to a 100-mL volumetric flask. Rinse the reaction beaker with about 5 mL distilled water then transfer contents to the volumetric flask. Repeat the rinse two more times. Finally, add enough water to the volumetric flask for the meniscus to reach the 100 mL mark. Cap the flask and invert several times to mix.
6. Use a pipette to transfer a sample of the reaction mixture to a cuvette. Measure absorbance at the optimal wavelength for Cu^{2+} . Record your results in your lab notebook.

***NOTE:** If the absorbance is below 0.1, repeat the procedure with double the sample mass. If the absorbance is above 1.0, perform a 50% dilution and measure the absorbance again. Repeat if necessary until the sample absorbance falls between 0.1 and 1.0. Don't forget to account for any additional dilutions in your calculations beyond this step.*
7. Dispose of all materials as directed by your instructor.
8. Use the linear equation to calculate concentration of the brass solution. Based on the r-value, is this an acceptable way to determine concentration? Show your calculations and plot the concentration as an "x" on your graph.

9. Calculate the percent copper in the original brass sample based on the sample concentration.

Hint: Track your dilutions of the original reaction product.

Extended Inquiry Investigation

Following the procedures used previously, similar investigations can be conducted to investigate the copper content of other everyday items. For example, the laboratory activity can be extended to determine the amount of copper in a penny, a piece of wire, or a small brass bolt from the hardware store. The item must be sufficiently small to facilitate the reaction with nitric acid. Have your lab group design a procedure to determine the copper content of your everyday item. As a team, you must determine if a new calibration curve must be created or if the standard curve developed in this lab's Initial Investigation will suffice for this analysis. Once the percent copper of your everyday item has been determined, compare your findings with theoretical values (online or literature sources) and calculate the percent error from your experimental determination. Record your procedures and results.

Synthesis Questions

1. A solution of potassium permanganate (KMnO_4) is purple. Describe the absorption spectrum of KMnO_4 within the visible light range.

2. An absorption spectrum shows significant absorption in the blue and little or no absorption in the green and red range. What color do you think the solution is?

3. MnSO_4 has a very faint yellow color. Which color of light is LEAST absorbed?

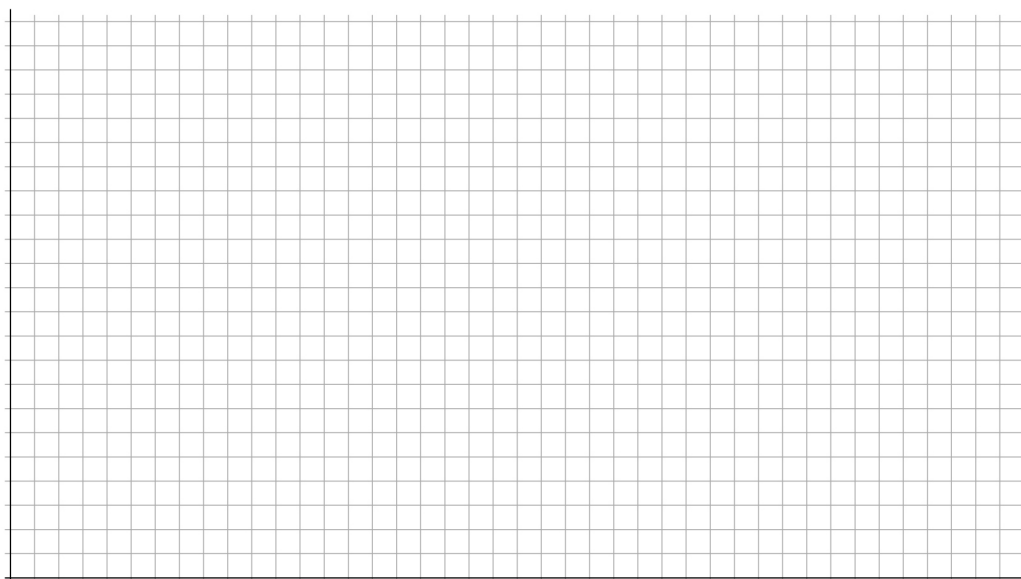
AP® Chemistry Review Questions

A Beer's law experiment is performed to determine the concentration of an unknown solution of nickel(II) ion in solution. The absorbances of 5 stock solutions of NiCl_2 are collected at a wavelength of 680 nm. The data is displayed below: Ni^{2+} ion has a molar absorptivity of $0.005292 \text{ L}\cdot\text{mol}^{-1}\cdot\text{cm}^{-1}$ at 680 nm.

Concentration of NiCl_2 (mM)	Absorbance at 680 nm
20	0.11
60	0.32
125	0.67
150	0.80
200	1.06

1. Plot the absorbance data in Graph 2. Include appropriate intervals, labels, and units for x- and y-axes.

Graph 2: Calibration Curve of Ni^{2+} Ions



2. The nickel(II) chloride solutions are green. Using the color wheel in the Pre-Lab Questions, explain why the sample absorbs best around 680 nm and not 500 nm.

3. Explain at the particle level, why the absorbance of a solution increases as concentration increases.

4. Assuming the y-intercept is negligible, predict the absorbance for a sample with a concentration of 163 mM.

5. Predict the concentration of a sample with an absorbance of 0.43.