PRELIMINARY ACTIVITY FOR

Beer's Law Investigations

Guided Inquiry Version

The primary objective of this Preliminary Activity is to determine the concentration of an unknown copper (II) sulfate solution. You will use a Colorimeter (a side view is shown in Figure 1). In this device, red light from the LED light source will pass through the solution and strike a photocell. The $CuSO_4$ solution used in this experiment is blue. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration. The Colorimeter monitors the light received by the photocell as percent transmittance.

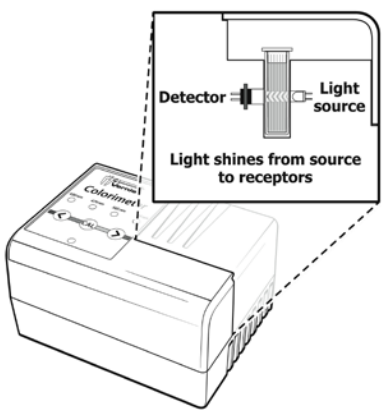

Figure 1

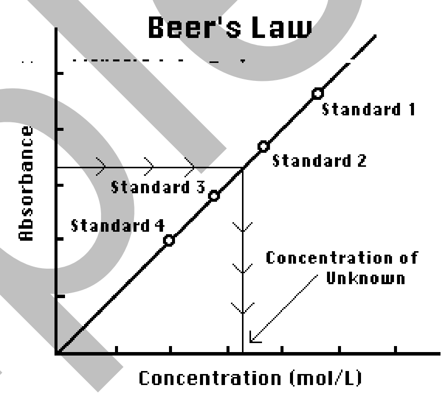

Figure 2

You will prepare five copper (II) sulfate solutions of known concentration (standard solutions). Each solution is transferred to a small, rectangular cuvette that is placed into the Colorimeter. The amount of light that penetrates the solution and strikes the photocell is used to compute the absorbance of each solution. When you graph absorbance *vs*. concentration for the standard solutions, a direct relationship should result. The direct relationship between absorbance and concentration for a solution is known as *Beer's law* (see Figure 2).

You will determine the concentration of an unknown $CuSO_4$ solution by measuring its absorbance with the Colorimeter. By locating the absorbance of the unknown on the vertical axis of the graph, the corresponding concentration can be found on the horizontal axis. The concentration of the unknown can also be found using the slope of the Beer's law curve.

After completing the Preliminary Activity, you will investigate your assigned researchable question. Use reference sources to find out more about solutions, solution concentration, and Beer's law investigations before planning and conducting your investigation.

PROCEDURE

1. Obtain and wear goggles.

2. Obtain small volumes of 0.40 M $CuSO_4$ solution and distilled water in separate beakers.

3. Label five clean, dry, test tubes 1–5. Use pipets to prepare five standard solutions according to the chart below. Thoroughly mix each solution with a stirring rod. Clean and dry the stirring rod between uses.

Trial number	0.40 M $CuSO_4$ (mL)	Distilled H_2O (mL)	Concentration (M)
1	2	8	0.080
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10	0	0.40

4. Set up the data-collection system.
   a. Connect the Colorimeter to the data-collection interface.
   b. Start the data-collection program.
   c. Set up data collection for Events with Entry. The entry name should be “Concentration,” and units should be “mol/L.”

5. Calibrate the Colorimeter.
   a. Prepare a *blank* by filling an empty cuvette 3/4 full with distilled water.
   b. Place the blank in the cuvette slot of the Colorimeter and close the lid.
   c. Press the < or > buttons on the Colorimeter to set the wavelength to 635 nm (Red). Then calibrate by pressing the CAL button on the Colorimeter. When the LED stops flashing, the calibration is complete.

6. You are now ready to collect absorbance-concentration data for the five standard solutions.
   a. Start data collection.
   b. Remove the cuvette from your Colorimeter and pour out the water. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Wipe the outside with a tissue, place it in the Colorimeter, and close the lid.
   c. When the absorbance readings have stabilized, select Keep and enter **0.080** as the concentration. Select OK. The absorbance and concentration values have now been saved for the first solution.
   d. Discard the cuvette contents as directed. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Wipe the outside, place it in the Colorimeter, and close the lid. When the absorbance readings have stabilized, select Keep and enter **0.16** as the concentration in mol/L. Select OK.
   e. Repeat Part d of this step for Test Tube 3 (0.24 M), Test Tube 4 (0.32M), and the stock 0.40 M $CuSO_4$. **Note:** Do not test the unknown solution until Step 7.
   f. Stop data collection.

7. Determine the absorbance value of the unknown $CuSO_4$ solution.
   a. Obtain about 5 mL of the *unknown* $CuSO_4$ in another clean, dry, test tube. Record the number of the unknown in your data table.
   b. Rinse the cuvette twice with the unknown solution and fill it about 3/4 full. Wipe the outside of the cuvette, place it into the Colorimeter, and close the lid.

c. Monitor the absorbance value. When this value has stabilized, record it in your data table.

8. Discard the solutions as directed by your instructor.

9. To determine the concentration of the unknown $CuSO_4$ solution, display a graph of absorbance *vs.* concentration with a linear regression curve. Move the cursor along the regression line until the absorbance value is approximately the same as the absorbance value you recorded in Step 7. The corresponding concentration value is the concentration of the unknown solution, in mol/L.

10. (Optional) Print a graph of absorbance *vs.* concentration, with a regression line and interpolated unknown concentration displayed.

QUESTIONS

1. What was the concentration of your unknown solution (in mol/L)?

Note: The plan that you submit for instructor approval should list laboratory safety concerns, including chemical safety concerns, and specify how you will address these safety concerns during your investigation.

Experiment
11

Beer's Law Investigations

OVERVIEW

In the Preliminary Activity, your students will learn technique for Beer's law investigations and determine the concentration of an unknown $CuSO_4$ solution. A student handout for the Open Inquiry version of the Preliminary Activity can be found at the end of this experiment. A Guided Inquiry version is found on the CD accompanying this book.

Although the Preliminary Activity is written for the Colorimeter, your students may gain a greater understanding of this investigation by using a Vernier Spectrometer or a Vernier SpectroVis. An alternate write up, which includes both Colorimeter and Spectrometer instructions, are found on the CD accompanying this book. *Appendix A* describes the location of these, and other, special lab files.

During the subsequent Inquiry Process, your students will first learn about solutions and possible applications of Beer's law technique using the course textbook, other available books, and the Internet. They will then generate and investigate researchable questions that utilize Beer's law technique. (In the Guided Inquiry approach, students will plan and conduct investigations of the researchable question(s) assigned by you.)

LEARNING OUTCOMES

In this inquiry experiment, students will

- Identify variables, design and perform the experiment, collect data, analyze data, draw a conclusion, and formulate a knowledge claim based on evidence from the experiment.
- Learn and apply Beer's law technique.

CORRELATIONS

IB Topic and Sub-Topic

Topic 1 – Quantitative Chemistry
Sub-Topic 1.5 – Solutions
Option A – Modern Analytical Chemistry
Sub-Topic A.2 – Principles of Spectroscopy

AP Chemistry Recommended Experiment

Experiment 17: Colorimetric or spectrophotometric analysis

THE INQUIRY PROCESS

Suggested Time to Complete the Experiment

See the section in the introduction, Doing Inquiry Experiments, for more information on carrying out each phase of an inquiry experiment.

	Inquiry Phase	Open Inquiry	Guided Inquiry
I	Preliminary Activity	40 minutes	40 minutes
II	Generating Researchable Questions (Omitted in Guided Inquiry Approach)	10 minutes	0 minutes
III	Planning	15 minutes	15 minutes
IV	Carrying Out the Plan	40 minutes	35 minutes
V	Organizing the Data	10 minutes	10 minutes
VI	Communicating the Results	15 minutes	10 minutes
VII	Conclusion	10 minutes	10 minutes

MATERIALS

Make the following materials available for student use. Items in bold are needed for the preliminary activity.

data-collection interface
data-collection program
Vernier Colorimeter
one cuvette
five 20 × 150 mm test tubes
test tube rack
two 10 mL pipets or graduated cylinders
two 100 mL beakers
$CuSO_4$ unknown solution
0.40 M $CuSO_4$ solution
distilled water
pipet pump or pipet bulb
stirring rod
tissues (preferably lint-free)
others as requested by students

I Preliminary Activity

This inquiry begins with an activity to reinforce prior knowledge of the use of Vernier data-collection technology and to introduce a method for collecting Beer's law data using a Colorimeter.

Sample Results

Table 1: Preliminary Activity Data		
Trial	Concentration (mol/L)	Absorbance
1	0.080	0.205
2	0.16	0.404
3	0.24	0.599
4	0.32	0.789
5	0.40	0.982
6	Unknown number 1	0.669

Concentration of the unknown	0.271 mol/L

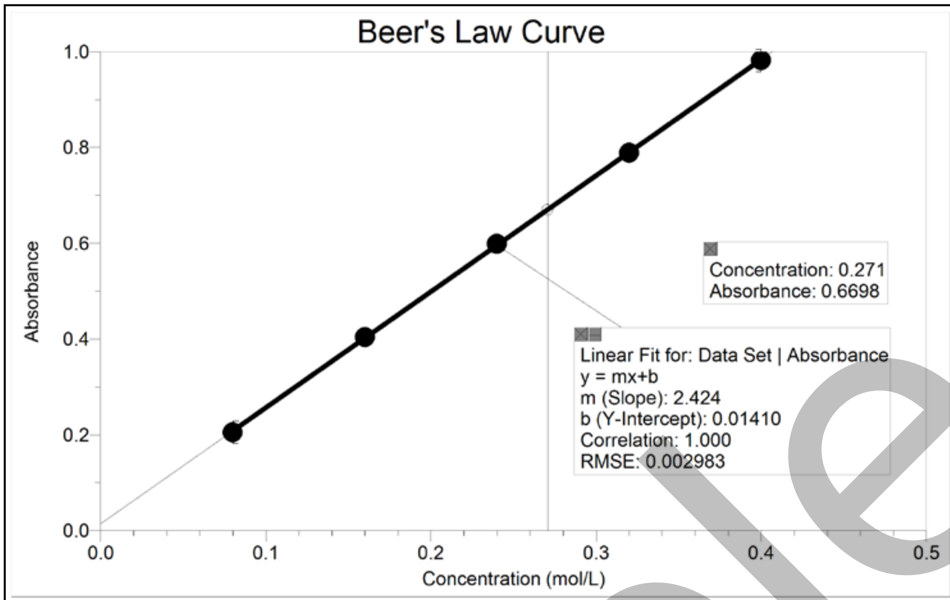

Figure 2 *Absorbance vs. concentration of $CuSO_4$*

Answers to the Questions

1. What was the concentration of your unknown solution (in mol/L)?

   Answers will vary. In the Sample Results above, the $CuSO_4$ concentration is 0.271 M.

2. Beer's law investigations involve the absorption of light by a colored species. The species may be colored itself, such as a colorful food dye in a beverage. Alternatively, the species of interest may be colorless, but able to react with an appropriate reagent to produce colored species. Some colorless ions in ground water fit into the latter category. An Internet search using "Beer's law experiments" as the search topic will reveal numerous possible researchable questions of potential interest to you.

   List at least one researchable question concerning the use of Beer's law technique. (Not applicable for the Guided Inquiry approach.)

   Answers will vary. See the Researchable Questions list below for some possible answers.

II Generating Researchable Questions

Note: Researchable questions are assigned by the instructor in the Guided Inquiry approach. See page xiii in the Doing Inquiry Experiments section for a list of suggestions for generating researchable questions. Some possible researchable questions for this experiment are listed below:

Recommended for Open Inquiry or Guided Inquiry (sample results provided)

- What is the free chlorine content of our swimming pool water (hot tub, spa, tap water, whirlpool)?
- What is the concentration of iron in a multivitamin tablet (iron tablet, local ground water, food)?

Recommended for Open Inquiry or Guided Inquiry (no sample results provided)

- What is the concentration of the $Cu(NO_3)_2$ ($CoCl_2$, $NiSO_4$) unknown solution issued to me by my instructor?
- What are the relative red #40 (allura red) concentrations in red #40-containing soft drinks?
- What are the relative yellow #5 (tartrazine) concentrations in yellow #5-containing soft drinks?

Recommended for Advanced Students (no sample results provided)

- What is the albumin concentration in egg white?
- What is the phosphate concentration in local ground water (a local lake, a local stream, a household product)?
- What is the nitrate concentration in local ground water (a local lake, a local stream)?

There are many more possible researchable questions. Students should choose a researchable question that addresses the learning outcomes of your specific standards. Be sure to emphasize experimental control and variables. (Instructors using the Guided Inquiry approach select the researchable questions to be investigated by their students. We encourage you to assign multiple researchable questions because this strategy enhances student interaction and learning during phases IV–VII.)

III Planning

During this phase students should formulate a hypothesis, determine the experimental design and setup, and write a method they will use to collect data. Circulate among the student groups asking questions and making helpful suggestions.

IV Carrying Out the Plan

During this phase, students use their plan to carry out the experiment and collect data. Circulate among the student groups asking questions and making helpful suggestions.

V Organizing the Data

See page xv in the Doing Inquiry Experiments section for suggestions concerning how students can organize their data for their inquiry presentations.

VI Communicating the Results

See page xv in the Doing Inquiry Experiments section for a list of inquiry-presentation strategies.

VII Conclusion

See page xvi in the Doing Inquiry Experiments section for a list of suggestions concerning assessment and ways to utilize the results in subsequent instruction.

SAMPLE RESULTS

Student results will vary depending on experimental design.

The Free Chlorine Content of Swimming Pool Water

Table 2: Free Chlorine Data

Trial	Concentration (mg/L)	Absorbance
1	0.40	0.030
2	0.80	0.067
3	1.20	0.121
4	1.60	0.161
5	2.00	0.210
6	Unknown number 1	0.066

Concentration of swimming pool sample	0.74 mg/L

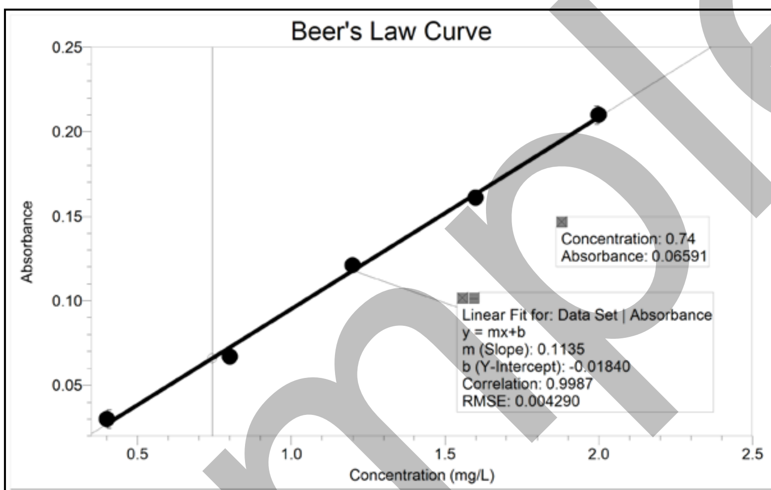

Figure 3 *Absorbance vs. free chlorine concentration*

This investigation addresses the question, "What is the free chlorine content of our swimming pool water?" The free chlorine content of the swimming pool water tested was found to be 0.74 mg/L. See the Tips section for details.

The Amount of Iron in a Multivitamin Tablet

Table 3: Iron Data		
Trial	Concentration (mg/L)	Absorbance
1	2.00	0.049
2	4.00	0.093
3	6.00	0.137
4	8.00	0.181
Tablet solution	5.45	0.125

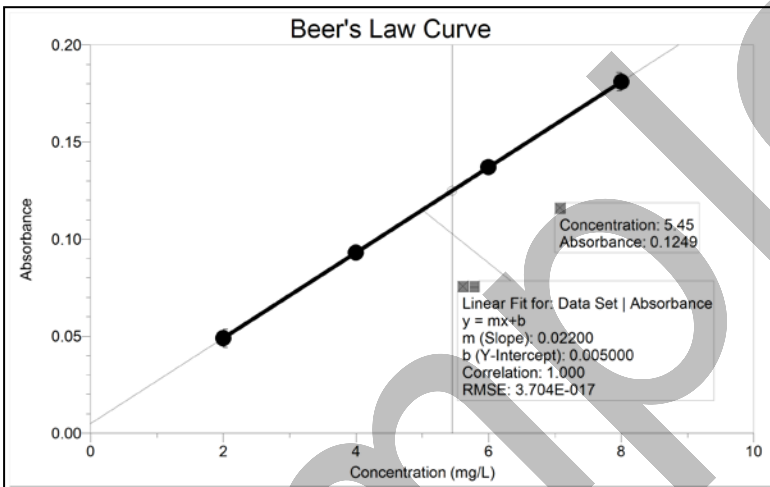

Figure 4 *Absorbance vs. iron concentration*

This investigation addresses the question, "What is the concentration of iron in a multivitamin tablet?" The iron concentration of the solution tested was found to be 5.45 mg/L, which corresponds to 17.7 mg of iron per 1.302 g tablet. The bottle label indicated the iron content to be 18 mg per tablet. See the Tips section for details.

TIPS

1. The light source for the copper (II) sulfate solution is the red LED (635 nm). The nearly monochromatic red light is absorbed by the solution.

2. Prepare 100 mL of 0.40 M copper (II) sulfate solution by dissolving 9.99 g of $CuSO_4{\bullet}5H_2O$ in sufficient distilled water to make 100 mL of solution. **HAZARD ALERT:** Copper (II) sulfate, pentahydrate: Skin and respiratory irritant; moderately toxic by ingestion and inhalation. Hazard code: C—Somewhat hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual*, (800) 452-1261, www.flinnsci.com. See *Appendix E* of this book for more information.

3. A suitable unknown $CuSO_4$ solution can be prepared by adding 50 mL of distilled water to 50 mL of the stock 0.40 M copper (II) sulfate solution.

4. You may substitute blue food coloring for the $CuSO_4$. Two recipes to try are: (a) 2 drops of food coloring per 100 mL of distilled water or, (b) 3 drops of food coloring per 150 mL of distilled water. Prepare each mixture and test them as the "0.4 M $CuSO_4$ solution." Decide which solution produces the optimum absorbance for the experiment.

5. The cuvettes should be at least 3/4 full to get good absorbance measurements. However, the cuvettes need not be completely full and indeed should not in order to seal the cuvette with a plastic cap without spilling out some solution.

6. We recommend that each student lab team use a single cuvette to test their liquids in the Colorimeter. This will eliminate errors introduced by slight variations in the absorbance of different plastic cuvettes.

7. There are two models of Vernier Colorimeters. The first model (rectangular shape) has three wavelength settings, and the newest model (a rounded shape) has four wavelength settings. The 635 nm wavelength of either model is used in this experiment. The newer model is an auto-ID sensor and supports automatic calibration (pressing the CAL button on the Colorimeter with a blank cuvette in the slot). If you have an older model Colorimeter, see www.vernier.com/til/1665.html for calibration information.

8. Experiment 33, Determining the Free Chlorine Content of Swimming Pool Water, in the Vernier lab book *Chemistry with Vernier* is one good source of information concerning the colorimetric determination of free chlorine content of water. Files for this experiment are found on the CD accompanying this lab book, *Investigating Chemistry through Inquiry*.

9. Experiment 34, Determining the Quantity of Iron in a Vitamin Tablet, in the Vernier lab book *Chemistry with Vernier* is one good source of information concerning the colorimetric determination of iron concentration. Files for this experiment are found on the CD accompanying this lab book, *Investigating Chemistry through Inquiry*.

10. Determining the Concentration of an Unknown Protein Solution: An application of Beer's Law, found in the Spring 2003 issue of *The Caliper*, the Vernier Software & Technology newsletter, is a good source of information concerning the colorimetric determination of albumin concentration. See www.vernier.com/caliper/spring03/beers.html.

11. Water Quality Test 7, Ortho- and Total Phosphates, in the Vernier lab book *Water Quality with Vernier* is one good source of information concerning the colorimetric determination of phosphate concentration. Files for this experiment are found on the CD accompanying this lab book, *Investigating Chemistry through Inquiry*.

12. Water Quality Test 8, Nitrate, in the Vernier lab book *Water Quality with Vernier* is one good source of information concerning the colorimetric determination of nitrate concentration. Files for this experiment are found on the CD accompanying this lab book, *Investigating Chemistry through Inquiry*.

13. See *Appendix F* for sensor and sensor check information.

14. The plans that your students submit for approval should list laboratory safety concerns, including chemical safety concerns, and specify how they will address these safety concerns during their investigations.