Nancy Konigsberg Kerner
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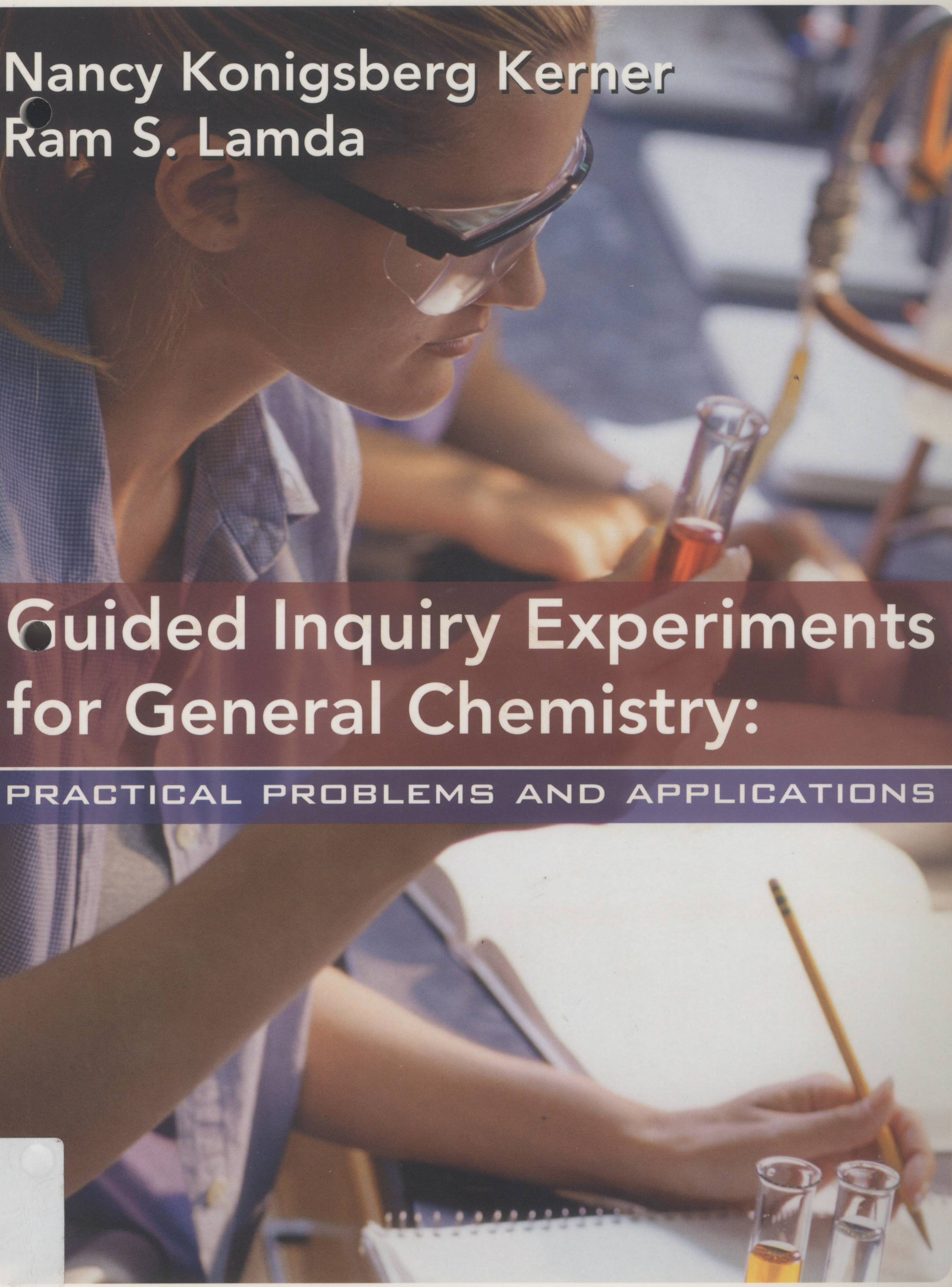
Guided Inquiry Experiments for General Chemistry:

PRACTICAL PROBLEMS AND APPLICATIONS



Guided Inquiry Experiments for General Chemistry: Practical Problems and Applications

First Edition

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THE WILEY BICENTENNIAL–KNOWLEDGE FOR GENERATIONS

Each generation has its unique needs and aspirations. When Charles Wiley first opened his small printing shop in lower Manhattan in 1807, it was a generation of boundless potential searching for an identity. And we were there, helping to define a new American literary tradition. Over half a century later, in the midst of the Second Industrial Revolution, it was a generation focused on building the future. Once again, we were there, supplying the critical scientific, technical, and engineering knowledge that helped frame the world. Throughout the 20th Century, and into the new millennium, nations began to reach out beyond their own borders and a new international community was born. Wiley was there, expanding its operations around the world to enable a global exchange of ideas, opinions, and know-how.

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Preface

GOAL

Our goal for writing this laboratory manual was to provide an exciting and meaningful laboratory experience for students by challenging them to solve a practical problem (''Why Did My Watch Stop Suddenly?'' ''How Deep Can a Diver Go?'') by drawing conclusions from experimental data. Each experiment ends with questions requiring feedback on the solution to the problem in the form of a report. A closing ''Extension and Applications'' section emphasizes the practical applications of chemistry by asking questions that require students to apply and extend experimental results to untested systems and real-world situations.

Guided Inquiry Experiments for General Chemistry: Practical Problems and Applications has been developed from our belief that it is valuable to use the laboratory as a process experience where students develop understanding of key chemical concepts from experiment. The approach encourages scientific thinking in which the emphasis is on asking ''what do the data mean?'' rather than on making ''chemically correct'' deductions. This approach also more closely reflects what occurs in scientific research. After conducting the labs, students report improvement in their communication and inquiry skills, including forming and testing hypotheses, analyzing data, and designing experiments.

INTENDED USERS, LEVEL, AND BREADTH

This manual covers two semesters (or three quarters) of a general chemistry program where a student can expect to spend three hours per experiment in the laboratory; extensive analysis and/or discussion of the implications of the data may lengthen this time.

The experiments may accompany any general chemistry text and are sorted into units based on topics common to most texts. Each unit offers several experiments on a given topic, where each focuses on a different key chemical concept. It is possible for a user to perform selected individual experiments in any order that best fits the background of students.

EXPERIMENT DESIGN

The experiment design is based on accepted educational theory that students construct their knowledge from involvement, experience, and models. The general framework of the experiments is inquiry (introduce a problem, collect data to solve the problem, organize and analyze data, apply and/or evaluate data). To further involve students in the inquiry process, guiding questions focus on the interpretation or ''what if'' of nearly every part of the laboratory procedure. We provide information, models, and guidelines rather than detailed procedures or explicit ''recipes'' to encourage active student involvement. Student dialogue and collaboration are encouraged in order to maximize the contributions that peer collaboration and teamwork can make in improving understanding. Students are often directed to compare and share observations and data to gather a large set of data that the students then analyze.

SAFETY GUIDELINES AND TECHNIQUES

Students are not expected to know laboratory safety guidelines or ''construct'' skills or techniques. Experiments in the introductory unit (Scientific Method) provide explicit directives and models for basic skills, including designing tables for data collection and guidelines for drawing graphs. Details are streamlined in subsequent experiments to promote active learning. Caution statements are placed in the text of the experiment procedure at appropriate positions to ensure that students are aware of immediate safety procedures.

EXPERIMENT CONTENTS

Introduction. One or more paragraphs establish the problem and experiment goals. An opening photograph reinforces the focus of the experiment.
Objectives. Students' goals are detailed with regard to solving the problem, performing the experiment, and collecting and analyzing data.
Procedures. A short paragraph provides an overview of the lab procedures.
Guidelines. We include guidelines for performing the experiment and collecting the data rather than explicit procedures to more actively involve the student.
Team Data. Directives or tables are provided for recording and organizing individual team data.
Compiled Team Data. In this section students organize the data from different teams.
Optional Extension. This optional problem challenges students to predict and experimentally test the impact of varying testing conditions on results.
Data Analysis and Implications. These are guided directives for interpreting data and "what if" questions regarding the data implications with regard to the problem to be solved.
Experiment Report. These directives for the laboratory report typically request the student to provide a summary of conclusions and recommendations with regard to the investigated problem and also include explicit reference to data collected and analyzed during the experiment.
Questions: Extensions and Applications. These are questions that require students to apply and / or extend results to untested samples and new situations.

TO THE STUDENT

Chemistry is an experimentally based science. We know what we know because many scientists have made millions of experimental observations over several hundred years. From these observations, fundamental understandings and principles have been realized regarding the properties and reactivity of matter. In turn, chemical understanding and principles can be used to solve real-world problems dealing with the properties and reactivity of matter.

The guided inquiry experiments in this manual will involve you in the process of looking for property or reactivity data patterns to solve problems. The experiments will also acquaint you with some of the processes (forming hypotheses, designing experiments, collecting and interpreting data, and explaining results) used by chemists to investigate chemical phenomena.

No one is born knowing how to perform chemistry labs (not even the instructors). Unlike some traditional laboratory approaches, you do *not* need to know anything about the problem being investigated in order to do well. You *do* have to prepare in advance for the labs, work conscientiously and safely during the lab period, and think about the experiments that you are performing.

When conducting research to solve a problem, chemists do not know the outcome in advance of performing the experiments. In contrast to some traditional laboratory experiments, here you are not expected to know the answer to the problem being investigated. If the outcome is known in advance there is no problem to solve. As with any research, there are a number of interpretations that will fit a data set. The "right answer" is any response that follows logically from the data and that clearly states your reasoning. An answer solely from a reference or textbook is unacceptable. Using information from a reference or textbook to support your data-based answer is acceptable.

Inquiry investigations consist of three phases: exploration, organization, and application. During exploration you will gather information (data) in order to answer the problem under investigation. During the organization phase, you will manipulate the data to look for patterns. Science consists, in large part, of attempts to arrange apparently diverse data so as to discover an underlying systematic order. The periodic table is an example of such a systematic order, where the elements are arranged by increasing atomic number and display a relationship between atomic number, structure, and properties. In the laboratory, you might consider whether the color of a solution can be linked to the structure of the species in the solution. If there is a link between color and structure, you should be able to make a rational prediction about the color of a sample you've never seen.

You can expect to experience confusion as you perform the labs and seek answers to problems. Confusion is a signal that you need to invest time sorting through the information and thinking about the implications of the results. Research indicates that your involvement in the process of resolving the confusion will facilitate development of your reasoning skills.

You will do most of your experiments as a member of a team. You and your team will combine and compare data, instead of competing for the "right" answer. Research has shown that students learn better, develop interpersonal skills, and enjoy a course more in a group (rather than individual) learning environment. In addition, teamwork typifies real-world science better than independent learning. Team learning does not mean that students simply work side by side on a problem or the best student works while the others watch. Rather, a well-functioning group is interdependent.

Instructor's Manual

A *Teacher's Manual* (available to instructors from Wiley) provides detailed information for each experiment and includes:

- An overview of the experiment
- Key chemical concepts the experiment develops
- Techniques/skills needed to perform the experiment
- Equipment and reagents needed per 24 students
- Reagent preparation including indicators, indicator substitutes, and unknowns
- Sample data
- Pre- and post-lab implementation suggestions
- Possible answers to questions
- Details for alternative low-cost equipment when applicable

To access the *Teacher's Manual*, please visit www.wiley.com/college/kerner. Click on the Instructor Companion Site to log-in and obtain your instructor password to view and/or download the manual.

Laboratory Equipment

Only simple laboratory glassware and equipment are necessary for completing most experiments. In addition to balances, spectrophotometers (Experiments 3-1 and 3-3), pH meters (Experiments 9-1 and 9-2), and pH electrodes and voltmeters (Experiments 11-1 and 11-2) are suggested. Low-cost alternatives to commercial pH electrodes using carbon (graphite) electrodes are described in the *Teacher's Manual*. If the instrumentation is unavailable, these experiments can be modified or omitted.

Acknowledgments

This manual is the result of several projects funded primarily by the National Science Foundation and developed chiefly at the University of Puerto Rico at Cayey, Inter American University of Puerto Rico, Metropolitan Campus, and the University of Michigan at Ann Arbor. The experiments have been thoroughly tested with undergraduate premed, engineering, and science (including chemistry), as well as non-chemistry, non-science, and future teachers majors. Successful use of the experiments has occurred outside the institutions of origin, including secondary institutions, community colleges, and universities.

We would also like to acknowledge the contributions of George Bodner from Purdue University, Jim Spencer from Franklin and Marshall College, and Cathy Middlecamp from University of Madison at Wisconsin to preliminary drafts of many of these experiments. We cannot thank Jim Spencer enough for his ceaseless encouragement to move forward with this project and help promote acceptance of the guided inquiry model and the methods of the project. We would also like to acknowledge the assistance of Carl Berger and graduate students in chemistry and education from University of Michigan at Ann Arbor, in the evaluation of the impact of preliminary drafts of some experiments on student attitudes and cognitive skills.

We also wish to recognize the contributions of Jairo Pardo and Nelson Granda, both from University of Puerto Rico at Cayey, and Agnes Dubey from the Metropolitan Campus of Inter American University of Puerto Rico for testing many experiments, giving feedback, and in some cases for the development of data for the *Teacher's Manual*. Special thanks are due to Shiva Sharma, a former graduate assistant at Inter American University of Puerto Rico, who tested and retested many of the original drafts of experiments with high school and undergraduate students. Special thanks are also due Ramon de la Cuetara from Inter American University of Puerto Rico for his collaboration and input on the construction and use of the low-cost equipment. We are indebted to the many undergraduate students who continuously gave us feedback toward improving the experiments, and, at the same time, giving us assurance that the approach helped them think more critically.

It is a pleasure to acknowledge the support, encouragement, and assistance of the staff at John Wiley and Sons for this guided inquiry lab manual. Thanks to Acquisitions Editor Kevin Molloy and Editor Stuart Johnson, for their commitment to this manual. Thanks to Hilary Newman, Photo Editor at Wiley, for assistance in obtaining the photographs for this edition; Barbara Russiello, Production Editor, for her attention to the design of the manual; Jeanine Furino, Production Editor, for her attention to managing the production, and to Cathy Donovan for attention to countless details.

Suggestions for revisions of preliminary drafts for these experiments were guided by student and instructor feedback and contributions from members of NSF Advisory Committees to the University of Michigan at Ann Arbor, University of Puerto Rico at Cayey, and Inter American University of Puerto Rico. Advisory Committee members included Rick Moog and Jim Spencer, Franklin and Marshall College; Mauri Ditzler, Millikan University; Joel Russell, Oakland University; and Michael Abraham; The University of Oklahoma.

We greatly appreciate feedback from the following reviewers:

Kristine Kirk
College of Notre Dame of Maryland

Roderick M. Macrae
Marian College

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Edward Baum
Grand Valley State University

Kathie Snyder
Winthrop University

Margaret Kerr
Worcester State College

Kathleen Brunke
Christopher Newport University

Patrick Barber
Longwood University

Cathy Middlecamp
University of Wisconsin at Madison

Kristine Kirk, College of Notre Dame of Maryland, served as lead reviewer, and her detailed feedback and guidance are especially valued.

Reviewer Comments

"There are few inquiry-based lab manuals available, and this one is perhaps the best I've seen. The use of scenarios to set each experiment in a context is engaging. The format appeals to students and helps them develop knowledge and skills that many instructors claim are essential, but few students actually learn and few instructors actually teach in traditional lab courses. The emphasis on science writing skills is a plus. Another plus is the emphasis on teamwork in the experiments, and collaborative work to gather a large set of data that the students then analyze."
Kristine Kirk, College of Notre Dame of Maryland

"I like the added real-world framework. The Extensions/Application sections are excellent, and would I think have a very positive impact on learning."
Roderick M. Macrae, Marian College

"This is a great way to teach lab to general chemistry students. It emphasizes a more realistic way in which a scientific problem is approached, and requires students to think, interpret and draw conclusions from data they obtained."
Kathie Snyder, Winthrop University

"I believe that students would be the real winners in a laboratory approach like this. They get to see the relationships and develop an understanding of the content rather than just memorize information. The approach is truly making the lab an extension of the lecture. They are not just validation labs which in my opinion are the least effective means of teaching."
Donnie Byers, Johnson County Community College

"This type of inquiry-based chemical laboratory experimentation will improve student's thinking and problem solving skills. It will also give them a sense of accomplishment when they complete a lab and its report especially as they must pretend that they are part of a company team and must make an oral / written report with supported recommendations to the group."
Patrick Barber, Longwood University

"This project is well thought-out, well-organized, and high quality. It is clear that the authors took the time to carefully design and test these labs. The risk you run with this material is that users who are not familiar with guided-inquiry instruction might be tempted to "improve" the labs by making ill-considered changes and additions. With a properly documented lab manual, the authors can take advantage of a valuable opportunity to educate their peers and help promote increased acceptance of the method."
Edward Baum, Grand Valley State University

We invite suggestions from colleagues, instructors, and students.

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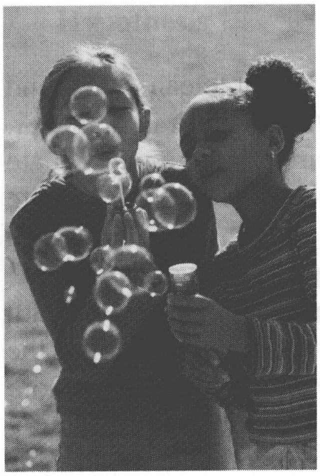
University of Puerto Rico at Cayey

Contents



Experiment 1–1

How Long Can a Bubble Last?

Introduction

You have recently been placed on a research team to help provide information for your company regarding their soap product. One customer recently returned the soap solution, claiming that the liquid produces bubbles that burst instantaneously. Your team's task is to carry out experimental procedures that can characterize the conditions needed to produce lasting bubbles.

Objectives

- Investigate the effect of soap concentration on the time that a bubble lasts.
- Design an experiment on bubble size and bubble longevity on different surfaces if time allows.
- Create a graphical plot of your bubble data to visualize and interpret the results.
- Report your findings and recommendations to the company.

Procedures

For purposes of comparison and validity of results, you need to be able to blow a single bubble of a given size from your soap solution. The information listed below indicates how to prepare your soap solution. Before starting your investigations, practice producing bubbles of consistent size as indicated in Preliminary Testing below.

Information

- To prepare a dilute soap solution, add 4 mL of Dawn™ liquid soap to a 100-mL volumetric flask and then dilute to the mark with water.
- If a magnetic stirrer is available, add a stir bar and slowly stir the solution for two to three minutes. You must stir slowly to minimize the formation of bubbles.
- Transfer the prepared soap solution to a beaker or Erlenmeyer flask.

Preliminary Testing

The surface on which the bubble is blown must be flat, clean, level, and away from drafts. Draw a circle on the surface that is 5 cm in diameter. You might achieve this by cutting out a 5-cm circle from a paper plate and then tracing the circle edge with a pencil. Obtain or prepare a dilute soap solution as indicated in the information above. Add 1 mL (20 drops) of the dilute soap solution to the center of your drawn circle. Place the tip of a hollow plastic coffee stirrer or a small straw beneath the surface of the soap solution. Blow *gently* and *continuously* into the open end of the coffee stirrer or straw to form a single bubble. (If more than one bubble forms when you blow through the straw, carefully clean the surface with a damp cloth so that no soap solution remains and start over.)

> *Caution:* Do not allow the soap solution to enter your mouth!

Use a stop or digital watch with increments of seconds to record the instant that the bubble becomes large enough to fill the circle. Then record the instant at which this 5-cm-diameter bubble bursts. One team member can blow the bubble and another record the lifetime of the bubble. Take turns and practice this measurement several times, until you have obtained and recorded consistent results.

Time (s) Bubble = 5-cm Circle	Time (s) Bubble Bursts	Lifetime (s) of 5-cm Bubble

Part 1 — The Effect of Concentration

What will happen to the lifetime of a bubble as you increase the concentration of the soap solution? You are to study four different soap concentrations (provided unless indicated otherwise) with a minimum of 4 mL to a maximum of 10 mL of Dawn™ diluted with water to a total volume of 100 mL.

1. Scientists generally start an investigation with a hypothesis. The hypothesis needn't be correct and can be disproved by experiment. What do you expect to happen to the lifetime of the bubble as you increase the concentration of the soap solution? Record your hypothesis.

Hypothesis

2. Read the following experiment guidelines and then proceed to measure the time it takes for a bubble of a given size (5 cm) to burst using different soap concentrations.

Guidelines

- For the purpose of sharing results, teams must use the same size bubbles, type of surface, and soap solution temperature for bubble production.
- You may share and compare the measurements taken at room temperature in Table 1 with those of other teams provided you use the same type of surface and size of bubble.

Team Data

Bubble size (cm): _____ Surface type: _____ Temperature (°C): ____

Table 1 The Time a Bubble Lasts versus Soap Solution Concentration

Trial	_________ mL Soap/100-mL Solution	Time (s)
1	4	
2	6	
3	8	
4	10	

Optional Extensions

1. If the soap solutions were prepared using varying water sources (i.e., distilled vs. hard vs. soft water) would your results differ?
2. Does the lifetime of a bubble depend on soap solution temperature? For example, if the soap solution temperature were higher, would your results differ?

Date: ____________ Name: ______________________________ Class: ______________

Data Analysis and Implications (Part I)

1. Create a graphical plot of your data regarding the lifetime of a bubble versus soap concentration.

   Note: The custom in drawing graphs is to use positions on the horizontal axis (x axis) to represent values of the independent variable, and to use positions on the vertical axis (y axis) to represent the dependent variable (calculated or measured values). Thus for this experiment the x axis is soap concentration (_mL soap/100 mL) and the y axis is lifetime of the bubble (seconds). Make sure your graph has properly labeled axes, is titled, and identifies the members of your team. Attach your graph to this report.

2. Post your results on the board (or as indicated by your supervisor). Compare your results with those of other teams. Do the graphs relate to one another in any systematic way? Describe any consistent or inconsistent pattern you observe.

3. Based on the posted graphs, what actually happened to the lifetime of the bubble as the soap solution became more concentrated?

4. Did the results support your predictions? Why or why not?

PART II—EXPERIMENT DESIGN: THE EFFECT OF SIZE AND SURFACE

Does the size of a soap bubble affect its lifetime? Does it matter whether a customer uses a particular type of surface to produce bubbles? Your instructor will ask different teams to investigate one of these two questions and share the results. Part IIA—The Effect of Size, and Part IIB—The Effect of Surface, ask you to design your experiment and collect data to provide an answer to these questions. You may include data already recorded in Part I for comparison purposes if your testing conditions such as soap concentration are identical.

Part IIA—The Effect of Size

Would a change in the size of the bubble affect its lifetime? If so, how? Your company requires you to report results for four varying sizes of bubbles with diameters between 3 and 7 cm.

1. What do you expect to happen to the lifetime of a bubble as you increase the diameter of the bubble? Record your hypothesis.

   Hypothesis

2. Read the experiment guidelines below and then proceed to design and conduct your experiment. Record your results for the effect of size on bubble lifetime in Table 2.

GUIDELINES

- Team trials must be conducted using controlled conditions (constant soap concentration, soap solution temperature, and surface type).
- Measurements already taken in Part I may only be used for comparison purposes if the same testing conditions are used.
- Teams collaborating on data collection must use the same testing conditions.
- Repeat the experiment procedure until you get consistent results.

PROCEDURE AND DATA