Introductory Physical Science

IPS EIGHTH EDITION

WITH FORMATIVE ASSESSMENT

Teacher's Guide

AND RESOURCE BOOK

URI HABER-SCHAIM
PETER GENDEL
H. GRADEN KIRKSEY
HAROLD A. PRATT

Science Curriculum Inc.
Belmont, Massachusetts 02478

Introductory Physical Science
Teacher's Guide and Resource Book

Eighth Edition

Uri Haber-Schaim Peter Gendel H. Graden Kirksey Harold A. Pratt

Credits
Editor: Sylvia Gelb
Book design: SYP Design & Production

Printed in the United States of America
by Daamen Printing

ISBN 1-882057-26-0

10 9 8 7 6 5 4 3 2 1

Contents

Preface
to the Eighth Edition

As in previous editions, the purpose of this *Teacher's Guide and Resource Book* is to provide you, the teacher, with the necessary background information to enable your students to get the most out of the IPS course. To this end you will find detailed suggestions for using reading sections, experiments, and problems in a variety of settings, as well as a general discussion of the content and pedagogy of the program. To explain the educational underpinnings of the course, we first present an Introduction that offers a broad perspective designed to introduce the course to those teaching it for the first time. The Introduction will provide a sound framework for the detailed suggestions that comprise the bulk of this Guide.

New to this edition of the *Guide* are questions for formative assessment, which will help you assess understanding, primarily of the reading sections, in real time. That is, these are questions that you may wish to ask the class while reading or discussing a given section.

Also new to this edition are a few brief articles titled "In Greater Depth." They will provide you with additional insight into topics related to the content of the chapter in which they appear.

We hope that you will find the perforated, three-hole-punched format of this *Teacher's Guide and Resource Book* useful in developing and compiling your personal notes and class results.

Uri Haber-Schaim
Peter Gendel
H. Graden Kirksey
Harold A. Pratt

Introduction to *IPS*

KEY PRINCIPLES

Even a casual perusal of the *IPS* textbook reveals how different it is from other textbooks. As a teacher new to the course, you may wonder about the source of the many differences: most of the characteristic qualities of *IPS* are the result of the consistent application of the following guidelines.

Having a clear set of objectives

The broad objective of *IPS* can be summarized as the development of laboratory skills, reasoning skills (*e.g.*, the application of knowledge to new situations), and communication skills in the context of science while gaining an understanding of the foundations of physical science. This guideline had a profound effect on the construction of the sequence, as will be explained in The Story Line of the Course.

Starting where the students are

IPS relies on the fact that all students have had some experience with matter in their daily life. But *IPS* has no prerequisites in the area of science content. In this program all new ideas are based on concrete student experiences in the laboratory, and all new terms are introduced only *after* the need for them has been established. This approach avoids the association of science with a technical vocabulary that must be memorized and is unrelated to the students' own experience.

Giving the students the time they need

The application of this guideline negates the *a priori* establishment of required coverage. From the development of the preliminary edition through this edition, we have allotted the time for a given topic on the basis of field-testing. A topic was eliminated if we thought that the time could be utilized more productively. A corollary to these considerations is the conclusion that students are better served by studying even a part of the course thoroughly rather than rushing through all of it.

THE STORY LINE OF THE COURSE

With its central theme of the study of matter leading to the development of the atomic model, *IPS* can be divided into two parts, providing a natural breaking point for those teachers who wish to integrate it with *Force, Motion, and Energy (FM&E)*.

Chapters 1–6 provide the empirical framework without which the atomic model becomes an answer in search of a question. The progression is from what is around us in the greatest abundance, namely mixtures, to compounds and elements. In the process, students learn about the characteristic properties by which substances are recognized and separated.

Chapters 7–10 use the discreteness of radioactive processes to motivate the development of the atomic model. The atomic model is shown to bring order to known facts and to allow us to make testable predictions. Simple methods are used to determine the sizes and masses of molecules and atoms. The periodic table is examined through a historical perspective and serves as a culmination of the course.

The story line is best described by the annotated table of contents beginning on the next page.

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 1 Volume and Mass 1.1 Experiment: Heating Baking Soda 1.2 Volume 1.3 Reading Scales 1.4 Experiment: Measuring Volume by Displacement of Water 1.5 Mass: The Equal-Arm Balance 1.6 Unequal-Arm Balances 1.7 Electronic Balances 1.8 Experiment: The Sensitivity of a Balance	As you introduce a new class to *IPS*, try to set the tone for the entire year on the first day. The short note "To the Student" (on page x in the text) and Experiment 1.1, Heating Baking Soda, will help you do that. The purpose of the note is to alert students to the interplay of the three forms of active learning in the course: experimenting, reading, and solving problems. You may wish to read the note in class either before or after Experiment 1.1. The purpose of the experiment is to raise questions, some of which will be answered later in this chapter. It also provides the first steps in developing laboratory skills. The last question in Experiment 1.1 serves as a motivation for the study of volume and mass. We begin with volume, showing different methods of measuring it and the need to say precisely what we mean by the volume of an object. After pointing out the shortcomings of volume as a measure of the quantity of matter, we then proceed to mass, which is operationally defined as that property of matter that is measured with an equal-arm balance. However, in practice, the course no longer requires the use of the equal-arm balance. Determining the sensitivity of a balance (Experiment 1.8) is written in such a way that it can be done with equal-arm balances, unequal-arm balances, or electronic balances.
Chapter 2 Mass Changes in Closed Systems 2.1 Experiment: The Mass of Dissolved Salt 2.2 Histograms 2.3 Using a Computer to Draw Histograms 2.4 Experiment: The Mass of Ice and Water 2.5 Experiment: The Mass of Copper and Sulfur 2.6 Experiment: The Mass of a Gas 2.7 The Conservation of Mass 2.8 Laws of Nature	Although this chapter is among the shorter ones in the text, it is of prime of importance. Interwoven are two objectives: the development of the skills related to the balance and the analysis of data, and the accumulation of evidence leading to a fundamental law of nature, the law of conservation of mass. It will take the entire chapter to reach the objectives. Histograms, which are introduced in this chapter, will be used throughout the course. The time you invest in teaching how to construct them will pay handsome dividends later on. Once the students know how to construct histograms by hand, we recommend that they use the KaleidaGraph software to save time and explore various choices available to them. Emphasize to students that a single experiment, involving only one kind of change (such as dissolving salt), is not in itself very convincing evidence for concluding that mass does not change when other changes take place. This is why four separate mass-conservation experiments, all involving different kinds of change, are included in this chapter. Do not skip any of them; let your students do all of them to convince themselves of the plausibility of conservation of mass.

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 3 Characteristic Properties 3.1 Properties of Substances and Properties of Objects 3.2 Experiment: Mass and Volume 3.3 Density 3.4 Dividing and Multiplying Measured Numbers 3.5 Experiment: The Density of Solids 3.6 Experiment: The Density of Liquids 3.7 Experiment: The Density of a Gas 3.8 The Range of Densities 3.9 Experiment: Freezing and Melting 3.10 Graphing 3.11 Experiment: Boiling Point 3.12 Boiling Point and Air Pressure 3.13 Identifying Substances	In daily language one hears statements like "lead is heavier than iron." Of course, lead is neither heavier nor lighter than iron, just as lead is neither bigger nor smaller than iron. Mass, volume, and shape are properties of objects. Properties that do not depend on the amount of a substance are called *characteristic properties.* The characteristic properties discussed in this chapter and in Chapter 4 have been selected for their usefulness in identifying substances and separating mixtures. Hence, we concentrate on density, freezing point, and boiling point in this chapter, and on solubility in Chapter 4.
Chapter 4 Solubility 4.1 Experiment: Dissolving a Solid in Water 4.2 Concentration 4.3 Experiment: Comparing the Concentrations of Saturated Solutions 4.4 Experiment: The Effect of Temperature on Solubility 4.5 Wood Alcohol and Grain Alcohol 4.6 Experiment: Isopropanol as a Solvent 4.7 Experiment: The Solubility of Carbon Dioxide 4.8 The Solubility of Gases 4.9 Acid Rain 4.10 Drinking Water	Solubility is a characteristic property of both the solute and the solvent. It is expressed in a complex unit—grams of solute per 100 cm^3 of solvent. If we know the solubility of a substance in a given solvent and the quantity we want to dissolve, we can calculate the minimum amount of solvent necessary. Or, if we know how much solvent we have, we can use the solubility to find the maximum amount of the solute we can dissolve in it. Like density, solubility changes with temperature. However, the solubility of some substances changes rather dramatically with temperature, whereas the density of solids or liquids changes only slightly. The dependence of solubility on temperature is very useful in separating substances in solution.
Chapter 5 The Separation of Mixtures 5.1 Experiment: Fractional Distillation 5.2 Petroleum 5.3 The Separation of Insoluble Solids 5.4 Experiment: The Separation of a Mixture of Solids 5.5 The Separation of a Mixture of Soluble Solids 5.6 Experiment: Paper Chromatography 5.7 A Mixture of Gases: Nitrogen and Oxygen 5.8 Mixtures and Pure Substances	As we mentioned earlier, one of the criteria for selecting characteristic properties for discussion was their usefulness in separating substances. Now we will employ these properties for actual separations in the laboratory, describe some applications of these methods in industry, and arrive at an operational definition of a pure substance. Reading through this chapter, you may get the impression that we are leaving students with a rather vague definition of a pure substance. This is true. The boundary between a mixture and a pure substance is not so sharp as may be believed from reading some textbooks. If your students realize at the end of this chapter that a pure substance is something that cannot be broken up by any of the methods discussed, they will have learned their lesson.

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 6 Compounds and Elements 	By definition, pure substances are not broken up into different components by those separation methods used to separate mixtures. The aim of this chapter is to show that, in general, pure substances can, nevertheless, be broken up by other means, such as applying intense heat or an electric current. Conversely, such pure substances (compounds) can also be synthesized from other pure substances, but only by reacting in definite proportions. After recalling the decomposition of two pure substances by heating, we use electrolysis to break up water (Experiment 6.2) New pure substances are produced that are quite different from the original substance. We then reverse our method of attack and synthesize compounds. The examples used are chosen to illustrate one of the basic differences between compounds and mixtures: unlike mixtures, compounds can be synthesized only by reacting the components in definite proportions (Sections 6.3 – 6.5). Early difficulties in the formation of the law of constant proportions sprang in part from the difficulty of determining when a reaction was complete. The reaction between copper and oxygen (Experiments 6.6 and 6.7) illustrates this circumstance: The investigation into what has happened leads to an understanding of complete and incomplete reactions. Experiment 6.9 ends the sequence of experiments that started with Experiment 6.6 and continued in Experiment 6.7. Copper was made to form a series of pure substances and was then recovered, suggesting that the copper was there all along. The section leads into the operational definition of elements (Section 6.10). The reasoning used in the definition of an element is reinforced with two historical examples. Be sure to spend enough time on this section. Sections 6.11 balances the preceding discussion of scientific methodology with a discussion of the abundance of elements near the surface of the earth.

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 7 Radioactivity 7.1 Radioactive Elements 7.2 Radioactive Decomposition 7.3 Experiment: Radioactive Background 7.4 Experiment: Collecting Radioactive Material on a Filter 7.5 Experiment: Absorption and Decay 7.6 A Closer Look at Radioactivity 7.7 Radioactivity and Health	You may wonder why we proceed with the introduction of radioactivity at this point in the course. Here are the reasons: (i) It gives an excellent example of the surprises that nature has for us: Just as students learned how elements survive in the formation of compounds they find that some elements change into other elements all on their own. (ii) This change takes place in discrete steps, which can be counted. (iii) The combination of (i) and (ii) provides a motivation for the atomic model of matter and leads to a testable prediction (Chapter 8). (iv) Being able to count radioactive decays enables us to find the number of atoms in a given sample of an element. This, in turn, provides a conceptually simple way to find the mass of single atoms solely with the knowledge students gained in this course (Chapter 9). (v) Knowing the mass of atoms enables us to introduce the periodic table in a meaningful way (Chapter10) In addition, it should be noted that radioactivity is largely ignored in the science curriculum. For many students, learning about radioactivity in *IPS* may be the only chance to do so. Randomness, discreteness, and absorption can be demonstrated quite easily in the classroom. However, decay and the existence of a half-life require a source with a short half-life. The only practical way to get such a source is to collect it yourself. You can do this if there is a sufficient concentration of radon in the ground around your school, and if your school has a closed, unventilated room in the basement in which radioactive material can be collected from the air. Unlike in other chapters, the three experiments in Chapter 7 are to be done by the class as a whole rather than by pairs of students. The reason is simple: it is unlikely that you will have enough Geiger counters. However, if you have more than one counter, divide the class into smaller groups and have them work in parallel. The class will have the advantage of seeing that while the details vary, the general trend is the same.

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 8 The Atomic Model of Matter 8.1 A Model 8.2 Experiment: A Black Box 8.3 The Atomic Model of Matter 8.4 "Experiment": Constant Composition Using Fasteners and Rings 8.5 Molecules 8.6 Experiment: Flame Tests of Some Elements 8.7 Experiment: Spectra of Some Elements 8.8 Spectral Analysis 8.9 "Experiment": An Analog for Radioactive Decay 8.10 Half-Life	We now introduce the atomic model of matter, which will continue to be at the center of our attention through Chapter 10. After a brief introduction to the meaning of a "model," the class applies the idea to a "black box," which provides an opportunity to make testable predictions (Experiment 8.2). Sections 8.3–8.5 sum up key observations made earlier in the course in the context of the atomic model. The law of conservation of mass and the law of constant proportions are given special attention. In Sections 8.6 and 8.7, the class experiments with spectra of atoms and is shown evidence that the spectra present properties of the individual atoms rather than properties of the elements in bulk. Finally, the atomic model is used to predict the existence of a half-life for radioactive elements.
Chapter 9 The Sizes and Masses of Molecules and Atoms 9.1 The Thickness of a Thin Layer 9.2 Experiment: The Thickness of a Thin Sheet of Metal 9.3 Experiment: The Size and Mass of an Oleic Acid Molecule 9.4 The Mass of Helium Atoms 9.5 The Mass of Polonium Atoms 9.6 Atomic Masses and Molecular Formulas	One of the key ingredients of the atomic model introduced in Chapter 8 was that atoms are very light and small, or, equivalently, that there are many atoms in any sample of an element of measurable mass. Building the atomic model on this premise demands an answer to the question "What is the mass of a single atom of an element?" In this chapter we answer the question. We arrive at our goal in stages, by preparing the students for the main experiment (Sections 9.4 and 9.5). We first find the thickness of an aluminum foil. We then apply the same approach to find the thickness of a layer of oleic acid (Sections 9.1–9.3). Sections 9.4 and 9.5 run parallel to the film, "The Mass of Atoms," which is now available in VHS and DVD formats and adds a lively dimension to the presentation in the text. Finally, the knowledge of atomic masses is applied to finding molecular formulas (Section 9.6).

TABLE OF CONTENTS	GENERAL COMMENTS
Chapter 10 The Classification of Elements: The Periodic Table 10.1 Introduction 10.2 Classifying Elements 10.3 The Extraction of Similar Elements from Similar Compounds 10.4 Alkali Metals, Alkaline Earth Metals, and Halogens 10.5 Activity: Atomic Mass and Other Properties of Atoms 10.6 The Elements in the Third Through Sixth Columns 10.7 Activity: Elements in the Fourth Row 10.8 The Fourth and Fifth Rows: A Historical Perspective	Chapter 10, which is new to the Eighth Edition, provides a climax to the year's work by tying together many observations on the macroscopic and atomic levels. We begin by asking if there is any relation between atomic mass and various properties of the elements (Section 10.1). This leads us to the question of how to classify elements (Sections 10.2–10.4). Some of the historical comments in these sections relate directly to similar comment made in Chapter 6. To drive home the point that any classification is a matter of judgment, we have the students do an activity with a set of 24 specially prepared cards (Section 10.5). The cards resemble entries in a periodic table of the elements. The activity has historical connotations, and raises the question of the order of potassium and argon. The activity is briefly extended in Section 10.7 to show the need for additional columns in the periodic table. The chapter ends with an analysis of the periodic table as a model, and showing its success by highlighting the correct prediction of the properties of germanium by Mendeleev before the element was discovered.
Appendix Part 1 Scientific Notation Part 2 Multiplying and Dividing in Scientific Notation: Significant Digits	The appendix provides instruction and practice for students who need to improve their skills in calculating with numbers in scientific notation.

COMPONENTS OF THE TEXTBOOK

Reading Sections

Some sections of the textbook are designated as “Experiments” and serve as guides to your students in their laboratory work. The other numbered sections lay the groundwork for new concepts, relate the results of experiments to students’ understanding of the nature of matter, or serve as introductions to or summaries of chapters. These sections are often brief, yet they are an integral part of the course. Disregarding the reading sections reduces the course to a succession of unrelated experiments.

Experience has shown that it is worthwhile to have students read some of these sections aloud in class and discuss them in detail. The For Formative Assessment questions in this *Guide* will help you note the degree of understanding of the reading sections almost paragraph by paragraph. Formative Assessment is discussed in detail on pages XX–XX.

Homework Problems

The text contains a large selection of problems—some are easy, short, and confidence-building; some are more complex; and, finally, some go beyond the course and serve as an optional extension of the material. This *Guide* identifies the various types of problems so that you can decide which problems will be most suitable for your class.

The problems and questions found at the ends of numbered sections within chapters generally cover single concepts and are designed to reinforce ideas immediately after they are encountered in the text or the laboratory.

The sets of problems labeled “For Review, Applications, and Extensions” (“RAEs” for short) located at the end of each chapter follow the order of presentation of material within the chapter. The RAEs are designed to extend the students’ knowledge to more general applications of the chapter and, in some cases, provide additional practice with important ideas. Many of the RAEs can be assigned to individual students based on their needs and abilities. Thus, it is not necessary to assign the same problems to all students. In particular, you can use the harder problems as extra assignments for students who wish to extend their understanding.

To derive the maximum benefit from the RAEs at the ends of the chapters, it is important to assign them when the subjects they deal with are being discussed in class. Call on your students to present their solutions to assigned problems and to defend them before the class. Many of the questions raised in the homework problems, as well as in the experiments, have more than one answer, depending on the assumptions a student makes. Do not be tempted to judge the students’ answers with a simple “right” or “wrong.” Instead, ask for the reasoning behind their answers. It is better to assign fewer problems and treat them in this way than to have the class do more and hand them in once a week simply to be graded. Assigning 50 to 80 percent of the problems seems to be appropriate, depending on the number and length of class periods and the ability of your students. Since topics and techniques from the early chapters of the text are used throughout the year, we recommend that from time to time you assign one or two problems from earlier chapters that are relevant to the current topic.

The Themes for Short Essays provide an outlet for creative writing in the context of science, and are best used in cooperation with a language arts teacher. We recommend that students be given the opportunity to revise their essays at least once. Some teachers offer extra credit for essays.

Teacher Demonstrations

In several cases, the textbook describes experiments not done by the class, giving actual data obtained with equipment shown in the illustrations. Try to demonstrate as many of these experiments as possible, or ask teams of students to prepare and present the demonstrations.

Index

Teachers new to *IPS* sometimes wonder about the absence of a glossary at the end of the text. The reason is simple: a glossary invites memorization by the students, and serves as a source for inappropriate quiz questions by teachers. We like to avoid both. The legitimate use of a glossary is well served by the extensive index.

THE ROLE OF FORMATIVE ASSESSMENT IN THIS COURSE

The Nature of Formative Assessment

Formative assessment, also known as "classroom assessment" or "everyday assessment," is a systematic way for teachers to do what good teachers have always done—monitor students' progress and assist students in meeting the course's goals. Research evidence strongly supports the view that formative assessment improves students' understanding and achievement.

What is distinctive about formative assessment is that it is forward-looking. The usual perspective of most assessment is backward-looking, toward what students have accomplished. In contrast, formative assessment is designed to help teachers and students work together to rapidly assess students' learning, identify learning weaknesses, and make plans for future instruction. Formative assessment is based on three guiding questions:

1. Where are you trying to go and what do you want to accomplish? (Identify and communicate to students the learning and performance goals together with the criteria for successful work.)
2. Where are you now? (Help students to self-assess their current level of understanding.)
3. How can you get there? (Help students with strategies and skills to reach the goal.)

This Eighth Edition of *IPS* introduces a variety of questions in both the text and this *Teacher's Guide and Resource Book*, along with methods for using them, to aid you in conducting formative assessment throughout each chapter. Before using these questions and strategies, it is important to have a thorough understanding of how formative assessment works.

Implementing Formative Assessment

There is no simple, single recipe for doing formative assessment. It occurs as teachers listen to students' responses, examine notebooks, mingle with students as they do experiments, grade quizzes, and use other strategies to find out "how it's going." Because one important goal of formative assessment is helping students to self-assess their own progress, they need to be a part of each of the above steps. Students need to know "where they are trying to go" in terms of what they are expected to know. They need to know the outcomes expected of them and how both they and the teacher will know if they have met the outcomes. Formative assessment questions are just one way of making clear to students what they should know and be able to do.

Next, students need to be able to determine how well they are progressing toward the goal. "Where are they" on the instructional pathway of many small steps leading to the learning goal? If, for example, being able to determine the density of an object is the expected outcome, there is a series of prerequisites students need to accomplish along the way that can be assessed. Can students determine the mass of an object? Can they determine the volume of an object? Can they divide two numbers and obtain a quotient with three significant figures having the correct unit and the decimal point in the correct position?

Students can be asked formative assessment questions in a variety of ways to assess their learning as the lessons on density progress. The simplest way is to ask students to show hands if they think they can do something or answer a question. That can be followed by asking the class to write the answer to one or two problems and let students self-score their answers. Ask each student to turn to a partner and answer a question or explain an idea. Rarely should these questions and answers be graded or have points assigned to them. They are designed to help the teacher and students assess their progress and catch up if they are missing an important step. This takes place at many steps along the instructional path so that immediate adjustments can be made, rather than waiting until the end of a series of lessons and looking back to see what was—or was not—accomplished.

Modifying instruction and sorting out the learning difficulties is the goal of formative assessment, not assigning grades. Assigning points or grades alters the spirit of the activity and the rationale for doing it, requires more time and effort on the part of the teacher, and reduces the effectiveness of the learning process.

The final step in formative assessment addresses the problem of helping the student "get where he or she needs to go." What can be done by, with, and for students who are having problems? A variety of procedures are possible. If a lack of understanding is evident for most of the class, whole-class instruction is called for. Often the problem lies not with the current instruction but in prerequisite skills that students are expected to have. The ability to divide numbers with decimal fractions is an example of a skill that formative assessment could identify as in need of supplemental instruction.

Formative Assessment in *IPS*

There are two sets of formative assessment questions in this edition of *IPS*: one set in the chapter commentary for many sections in this *Teacher's Guide and Resource Book* and another at the end of many sections of the text, where the questions are color-coded in yellow for ease of identification. The first set, which is almost always associated with a particular reading section, is designed to determine whether students comprehend individual steps in the development of specific ideas. Therefore, each question is assigned to a particular paragraph in the reading section and designated by a reference such as "*1st par.*" preceding the question. Questions designed to be used at the end of a section are preceded by a "*Sec.*" designation. If you are reading the section together with the class, use each question after reading the specified paragraph. The field-testing of our formative assessment questions showed that they had the additional benefit of inspiring teachers to develop extra questions on their own.

We suggest that you ask each question orally to the class and determine how many students understand the reading passage. Be sure to allow sufficient time for students to respond! Once one student has answered, you may wish to ask whether anyone else has a different answer, without giving away your opinion of the validity of the first answer.

An alternative strategy is to direct students to write the answer or tell it to a classmate. After a show of hands to assess how many students correctly answered the question, note to yourself the success rate of the class and decide if additional discussion and/or instruction is needed. To avoid having to hold the *Guide* in your hand during the reading, you may find it useful to copy the questions on an index card.

The second set of formative assessment questions appears in the text to assess how well students understand a key point or the reason for a step in a procedure. The use of these questions enables you to quickly identify how well students are learning the lesson, diagnose where students are having trouble, and make plans to modify future instruction. If the point in question is needed for successful learning later in the course, you may modify your instruction so that the majority of the class understands the idea before proceeding. Keep in mind that complete mastery may not be needed because subsequent use of the idea will provide an opportunity to reinforce instruction.

In some cases, a small number of students may be having specific problems and can be paired with students who already have a good grasp of that particular concept or skill. Sometimes making a mental note of who is having what kinds of problems will help as you make the rounds during an experiment or other activity. You may decide to check certain students' notebooks more frequently than others as a result of your assessment work.

Keep in mind that your long-term goal is helping your students to assess their own learning. Self-assessment has been shown to be one of the most effective means of improving student success.

THE ROLE OF LABORATORY WORK IN THIS COURSE

Pivotal Role of Experiments

Our knowledge of physical science is the result of years of experimentation. No student can experience all the discoveries that have been made to date, but as far as possible we should like him or her to learn physical science in the laboratory. Your students' ability to understand the discoveries of others rests on their having real experiences themselves. They profit most by making their own observations and drawing their own conclusions.

In this course, the laboratory work is an integral part of the text. Some of the significant conclusions your students arrive at in the laboratory do not appear explicitly in the accompanying text. In other words, it is assumed in many cases that students have found in the laboratory facts or laws on which subsequent sections of the text are based.

Providing Guidance

The laboratory instructions in the textbook provide a minimum of directions and, by raising questions, call students' attention to the important points in an experiment. Sometimes the answers to these questions require thought only; at other times experimentation is needed. Your students must decide what to do. At the beginning of the course, some students may feel a little insecure with this type of laboratory work. They are likely to ask whether they have the right result. You must help them to realize that nature cannot be wrong; our job is to understand nature by measurement and interpretation. If students have not measured what they set out to measure, a discussion, rather than a yes-or-no answer, is in order.

Responding to Students' Questions

Your students will ask for answers, and will continue to ask for them if you give them. If you let students find their own answers, they will not only learn more but also gain confidence in their ability to make useful decisions. At first you may find this difficult, but if, after listening to their questions, you respond a few times with answers such as, "How can you find out?" or "Try it." or "Look it up." or "You have to decide." or "Are you satisfied with the data?" your students will become resourceful.

Collecting Class Data

Experiments should be done at the time they are encountered in studying the text. In this way, your students are not likely to know what to expect. As they progress in the course, they learn to enjoy doing experiments whose results they do not know in advance, even though they realize that someone has faced and solved the same problem before them.

Experimental data are usually collected by individuals or by pairs of students working in the laboratory. The task of collecting sufficient data is simplified by having the members of the class share the workload. These data are then pooled, often in the form of tables, graphs, or histograms from which generalizations can be drawn. For example, suppose a student seeks to determine whether the freezing point of a liquid depends on the amount of the substance (Experiment 3.9). He or she would have to make a number of determinations requiring several days. A properly planned class experiment will provide in one period data on a dozen samples of different sizes, which can then be pooled in a "post-lab" that will help the whole class reach a conclusion.

In addition to simplifying the collection of data, the class effort provides a very useful forum for discussion of ideas and results. The give-and-take atmosphere is vital if students are to learn how knowledge is acquired. Through these discussions, students learn from each other as well as from the teacher.

Planning Laboratory Work

Since the course is centered around experimental work by the students, it is of the utmost importance that the specified equipment be on hand and easily accessible. Although a well-designed science laboratory always is an asset, this course can be taught successfully in a classroom with one sink, flat tables, and a reasonable amount of storage space.

A fair fraction of a class period usually is lost in setting up equipment and taking it down. This fraction is considerably reduced if double periods can be arranged.

To assist you in planning and conducting the experiments, the Guide includes information on apparatus, expected duration of the experiment, necessary materials, and recommended procedure.

Your students usually should be able to do an experiment in a 45–50-minute class period; however, when this is not possible, the *Guide* indicates the best point at which to interrupt an experiment. In many of the experiments, the *Guide* also indicates the degree of precision you may reasonably expect.

Most of the experiments are designed to be performed by two students working together. In many experiments, one pair of hands is not enough to carry out the necessary manipulations, but more than two students working together can lead to confusion and wasted time.

There is some advantage in individual work in the laboratory; it forces every student to come to grips with the whole experiment and prevents one of the partners from becoming a mere note-taker. On the other hand, working in pairs gives the students more confidence in their work, and they can learn from each other by discussing their data. In short, they learn to work cooperatively. However, a notebook has to be kept by each student.

SAFETY PROCEDURES

Since the best thing to do about accidents is to prevent them, the *IPS* experiments are designed to minimize classroom hazards. Note, however, that a potential hazard exists whenever students are working in a laboratory. The choice of experiments and the quantities of chemicals utilized have been made after careful consideration for the safety of all involved and after thorough testing in the developmental stages, including classroom field-testing. This Guide includes a complete list of equipment and chemicals and the minimum standard of quality (pages XX and XX). Our experience has shown that the major cause of accidents is the improper use and handling of the materials. We therefore urge you to review and practice the following general safety procedures with your class.

- Be sure that you and your students follow all local and state fire and safety regulations.
- Store all chemicals in a locked cabinet (preferably in a vented storeroom), grouped by category, and in the original containers to avoid mislabeling.
- Dispense chemicals at several stations in the classroom. This will reduce the crowding and pushing that cause spillage. (When your students measure out chemicals from a common source, care should be taken that the source is not contaminated. Students should NOT pour unused portions back into the containers they came from.)
- Always use glycerine as a lubricant for inserting glass tubing into rubber stoppers. Towels should be used to protect against cuts due to breakage of tubing.
- Where possible, utilize plastic or unbreakable containers for dispensing materials.
- Do not allow students to substitute chemicals in experiments unless you have thoroughly checked the procedure.
- Use only microburners NOT full-size Bunsen burners.
- Always make sure that microburners are turned off at the source of the gas, NOT at the burner itself.
- Use only burner fuel, which is denatured ethanol. DO NOT use ditto fluid or other liquids that contain mainly methanol.
- NEVER dispense burner fuel from the one-gallon metal cans. Pint-size plastic bottles should be filled (in a storeroom, if possible) away from any flame, labeled plainly, and placed at each chemical-dispensing station in the classroom.
- Have fire extinguishers and sodium bicarbonate solution (for acid burns) conspicuously placed and handy in each classroom.
- Insist that your students wear safety glasses whenever these are included in the list of apparatus and materials for an experiment in this *Guide*. Be sure to wear them yourself when required.
- NEVER allow students to taste anything.

PRE-LAB AND POST-LAB DISCUSSIONS

Importance of Discussion

One of the most important aspects of teaching this course is conducting a discussion of an experiment before the class attempts it (a “pre-lab”) and then, after the completion of the experiment, reviewing it with the class and discussing the conclusions that may be drawn from it (a “post-lab”).

Students do not automatically learn something simply by doing an experiment, even though they may have obtained very good results. In order to interpret the results and realize the implications of them, each student must understand why he or she is doing an experiment before starting it. In the pre-lab preceding each experiment, it is advisable to involve the students in the design of the experiment as much as possible. In this way, they develop a better understanding of the purpose of the experiment, the procedures they will follow, and the kind of data they will have to collect. The pre-lab provides an opportunity for students to exercise their imagination and ingenuity. It also provides an opportunity to identify the equipment needed and to review important safety procedures that are appropriate for the experiment.

Characteristics of the Pre-Lab Discussion

Raising questions and leading a class discussion during the pre-lab are effective ways to help the students understand the experiment and any new techniques required to carry it out. (Sometimes, as in the case of safety precautions, this is not advisable—you must simply tell them how to do something.)

Some experiments, such as 1.8 and 5.4, are designed to familiarize the students with an instrument or technique; others, such as 4.7, 6.6, and 6.7 generate data and observations that can lead to fruitful questions or analyses. Most experiments, however, are designed to help answer a specific important, basic question. Once students understand a question clearly, there is no reason why they cannot share in the excitement of designing an experiment to find an answer.

Some experiments are more quantitative in nature and require careful recording of data, drawing of graphs, and calculating of results. This is true of the experiments on conservation of mass in Chapter 2.

In your discussion of an experiment in the pre-lab, do not give away the expected results. (However, you do not have to pretend, with any class, that the results are not known.)

In most cases, before you conduct the pre-lab discussion, you should insist that your students read the instructions for the experiment given in the text and think about why and how it is to be done.

Pooling Data

As we have said, answering questions in many of the quantitative experiments in the course requires the collection of all the data for different conditions obtained by the whole class. Even when all the students do exactly the same experiment, they usually have time to take only one set of readings. Individual results vary, and only the pooling of the results of all stations in a post-lab will lead to useful conclusions.

Perhaps the best way to pool individual results is to draw a histogram showing the results of the entire class. Such a histogram shows how separately determined values cluster around the most probable value—something that is not shown by individual results or by an average value calculated from the data of the whole class. Examples of class histograms are given in the discussion of the results of experiments in which histograms are useful.

It is sometimes valuable to have the entire class repeat an experiment when the pooling of class results does not lead to a firm conclusion. In such cases, class discussion of possible errors in procedure or measurement will lead to better results when the class tries the experiment again. It is particularly important in such circumstances not to divulge the expected results; if you do, students who have come close to the expected result will lack the incentive to repeat the experiment.

SOFTWARE FOR HISTOGRAMS

As indicated at the end of the discussion of the post-lab, histograms are used throughout the course to display data collected by students as part of their laboratory work. When students are first learning to use histograms, constructing one or two of them by hand is a useful exercise. Once students have mastered the basics, the tedious and time-consuming work of constructing, altering, and refining their histograms can be better done with *KaleidaGraph* software from Synergy Software.

KaleidaGraph is powerful, user-friendly software that allows students to quickly and easily generate and modify histograms using *the same approach that is presented in the IPS text.* Just as they do when constructing histograms manually, students using KaleidaGraph choose the appropriate bin size and reference value, and decide whether to place the reference value in the center of a bin or on the border between bins. (For a discussion of bins and reference numbers, see Sections 2.2 and 2.3 of the student text.) Other available options include adding empty bins at the ends and selecting from a range of fonts and colors. Visit our website for details on purchasing *KaleidaGraph*.

STUDENT LABORATORY NOTEBOOKS

Good Notebook Practices

It is imperative that all students keep a notebook containing a legible and complete record of what they do at the time they do it. The value of a good notebook is that students can refer to it at a later time and reconstruct the experiment from the recorded data and observations.

Do not insist on neatness in notebooks. It will only drive your students to recording data on scraps of paper (easily lost) and copying the data into their notebooks later, a practice that should never be allowed.

Whether the notebook is written in ink or pencil is not important. It need not be a work of art; neatness and organization need only be sufficient to allow a student's experiment to be completely reconstructed. There is nothing wrong with abbreviations and marginal notes as afterthoughts as long as the description is clear. The goal is to produce a useful laboratory notebook, not a formal report.

Avoid the common practice of having students put their records in order under headings such as "Object of Experiment," "Apparatus," "Diagram of Apparatus," or "Procedure." This tends to replace thought with a concern for mechanical details. There is no reason why every student's write-up of a given experiment should have the same form. All the details should be clear enough if the text instructions (and the illustrations and their captions) are read in conjunction with the laboratory notebooks. However, if the procedure used differs from that in the text for any reason, such as a student-suggested change in procedure (approved by you!) or a change in apparatus used, then this change should be briefly noted in the students' notebooks.

Encourage imaginative students who wish to vary the procedure for sound reasons or to extend the experiment in order to answer additional questions (perhaps coming back in their free time to do so).

When checking students' notebooks, you should point out errors in spelling, grammar, and sentence structure, particularly if they contribute to a lack of clarity.

All measurements taken should be recorded with appropriate units and must include the name of what is being measured.

Recording and Organizing Data

Data in notebooks are obtained from one of two sources: (1) a direct measurement or (2) a calculation. If from the latter, the entry in the notebook should show the source of the calculated figure, unless it is obvious.

The arrangement of the data should be such that anyone who understands the experiment can quickly reconstruct it without any doubt as to the procedure followed, measurements made, or calculations performed. While there are many arrangements that will accomplish this, three are especially well-suited to this purpose:

(1) A sequential listing of the data, calculations, and observations.
(2) A table that contains these same elements, when appropriate.
(3) Answers to questions and a conclusion, if appropriate.

If the experiment is to be run only once, a listing of the steps taken, along with the data and calculations, is usually best.

If the experiment requires that the same procedures be repeated several times, arranging the data in a table is often convenient, since it makes it easy to compare the results of different runs.

Let your students decide in the pre-lab, or individually, the best format for recording data and calculations in each experiment.

Using the Bulleted and Other Questions

Answers to questions asked in the text, as well as class data and class conclusions reached in the post-lab, should also be included in the laboratory notebook. Recording the conclusions is essential, since they are often important for work later on and may not be explicitly stated in the text.

Introductory questions, sometimes rhetorical, establish a basis or rationale for doing the experiment. The bulleted questions that follow can only be answered during or after the experiment. Although students should give some thought to the introductory questions, they are not usually expected to have a definitive answer to such questions until the experiment has been concluded. For example, the beginning of Experiment 3.9, Freezing and Melting, reads, “If you live in a part of the country where it snows in the winter, you know that a big pile of snow takes longer to melt than a small one. Does this mean that the big pile melts at a higher temperature?” Before doing this experiment, students probably have no evidence from which to answer this question. The question only introduces the purpose of the experiment.

Of course, the fact that a question is asked at the beginning of an experiment does not necessarily mean that it is rhetorical and that it does not require an answer. For example, in part A of Experiment 5.1, Fractional Distillation, students are directed to examine a liquid and are asked in a bulleted question: “Can you tell just by looking at it that the liquid is a mixture?” This question, of course, requires an answer, which should include the observation that prompted it. Also, there are questions that require students to make observations that are necessary to their understanding of the experiment. In such cases, it is important that students answer the question in their laboratory notebooks, chronologically, at the time they make observations. Do not allow students to make a numbered list of answers to all the questions at the end of the experiment. Insist on self-contained answers that leave no doubt as to which question is being answered. (See the footnote on page 4 of the text.)

Reaching Conclusions

Since the conclusions reached in the post-lab usually are based on experimental data from the entire class, class data needed to support them should also be included in the notebook. This will also stress the need for having a large amount of supporting evidence before stating a generalization. The conclusion written in the notebook should be an accurate and complete statement of the generalization made by the class in the post-lab discussion.

Checking Students’ Notebooks

Many students will have had no previous experience in keeping a laboratory notebook. Therefore, it is important that the first few write-ups of experiments be given immediate and careful attention. This can best be accomplished by glancing at students’ notebooks, asking questions, and making suggestions while they are doing an experiment. The extent to which this can be done will depend on the experiment. For example, if a measurement is being made every 30 seconds, it would disrupt the work to question students about their notebooks. If possible, sit down with individual students out of class and carefully go over an experiment, asking them questions about the entries in their notebooks and making suggestions as to how they might correct deficiencies. If this is not possible, collect the notebooks and write suggestions for improvement in the margins. Then see how well the improvements are made.

ASSESSING ACHIEVEMENT

Focus on Progress

Achievement in this course manifests itself in many ways, some of which are not subject to quantitative measurement. Consider, for example, the student who, at the beginning of the year, is quite lost in the laboratory and finds it hard to make a move without explicit instructions from you. A few months later, you see the same student working independently and knowledgeably; the student has certainly progressed. Another tangible is the improvement shown in students' skill in communicating orally the results of their laboratory work or the reasoning behind the solution of a problem. Progress in these domains, although hard to gauge quantitatively, should certainly be considered in arriving at a student's grade.

It is good practice, in regard to evaluations that are subjective by nature, to reward and encourage students who make progress in these areas, but not to downgrade those who do not. Students are individuals with individual differences, and their work cannot all be judged on the same basis.

Managing the Paperwork

Your paperwork in teaching this course need not be a burden if you are selective in what you read and mark. It is unnecessary and, in fact, impossible to read and correct every detail of all questions and RAEs that students do and all the experiments in their laboratory notebooks. Read only a few notebooks and homework papers at a time. When you do correct students' written work, do a thorough job. You must make detailed and serious comments if you wish your students to respect them. Be sure to check from time to time to see whether students have heeded your suggestions.

You can do much of the work of evaluating laboratory skills by checking your students' laboratory notebooks and their handling of different techniques as you move around the laboratory observing, questioning, and helping them (only when they really need help!).

Using the Assessment Package

To help you to determine your students' overall comprehension of the course and their ability to apply their acquired knowledge to new situations, we have developed a comprehensive *Assessment Package*. The package covers the entire course and is consistent with its objectives. There are two sets of ten chapter tests, consisting of multiple-choice questions and essay questions. The two sets differ in the degree of difficulty. In addition, there is a set of lab tests. For details and specific suggestions on the use of the tests see the preface to the test package.

We have found that it is time-consuming to generate high-quality questions in the spirit of the *IPS* course. If you wish to write questions, be sure that you put the emphasis on the broad topics that are stressed in the text and in the laboratory experiments. If you write questions that rely too heavily on memory and recall, your students will quickly catch on to the fact that the way to get high grades is to cram for your tests. "Open book" and "open lab" tests can be used to advantage in this course.

Appropriateness for "open book" tests makes a good criterion for assessing any question you write.

The *Diagnostic Analysis* Software

The *Diagnostic Analysis* software provides an additional tool for evaluating the degree of student understanding and for identifying the nature of any difficulties. The software is available for both Windows and Macintosh operating systems.

Assigning Grades

This course is definitely not suited to a straight averaging of all grades at the end of the year. Combining the averages of all ten *IPS* multiple-choice tests, laboratory tests, and essay tests, and the laboratory-notebook grades (if you grade them), does not give a useful result. Rather than being made up of nearly independent "units," the course develops throughout the year as a series of closely and logically connected steps. The later parts of the course are built on the foundations laid in the earlier parts in such a way that most concepts, once introduced, keep reappearing throughout the course. The Epilogue of the student text may help you make a judgment of your students' achievement.

In reviewing your students' laboratory notebooks, RAEs' solutions, and oral presentations, you should, as mentioned, point out errors in spelling, grammar, and sentence structure, particularly if they interfere with clarity. However, in assigning grades, it is best to give no weight to such errors per se, but only to whatever lack of clarity results.

THE INDIVIDUAL IN THE CLASS

It probably has become clear from what has been said so far in the Introduction that the *IPS* course offers a wide variety of experiences to the individual while providing him or her with the benefits of interacting with the class as a whole. However, for the sake of emphasis, it is worthwhile to summarize the various ways in which you can personalize your instruction.

These ways of personalizing your relations with your students will serve individual needs while making full use of the class as a learning community. We feel that this approach answers the needs of the individual far better than letting individual students go at their own pace through the same material to the same depth.

In the Laboratory

Once the general purpose of an experiment is established in the pre-lab and the class begins to work, you can divide your time among the students according to their individual needs. Spend little time with those who are well on their way. Help, with a few leading questions, those who are encountering difficulties. Most experiments are open-ended; that is, there is always something useful to do for those who have finished the minimum assignment ahead of the others. Encourage them to go on.

Individual Contributions to Class Discussions

Every class has its extroverts and its introverts. Since being able to communicate ideas is an important goal of this course, call on students selectively to give those who need it more opportunity to present their solutions to problems or the results of their experiments to the class.

Accommodating Individual Interests

The degree and direction of interest of individual students in the course will vary. Permit some of them to concentrate on the qualitative, and treat lightly the abstract ideas and the mathematical details. On the other hand, let others go into greater depth. Challenge them with harder RAEs. Let them help you in setting up class demonstrations and in teaching their peers.

SCHEDULING THE COURSE

The most appropriate speed with which to proceed in the course varies over a wide range and depends on the ability of the students, the size of the class, and the number and length of class periods. Therefore, the overall schedule suggested here, which includes two periods for each chapter test but does not include the laboratory tests, should be regarded as a very general framework.

Chapter	Periods	Chapter	Periods
1	12	6	17
2	11	7	10(8*)
3	18	8	14
4	13	9	10
5	16	10	8

*With the minimum amount of experimental work.

A more detailed schedule appears at the beginning of each chapter discussion in this *Guide*. These detailed schedules also should be used for general orientation only.

List of Equipment

ITEM	NO.NEEDED
Balance, Equal-Arm	1
Balance, Single-Pan	12
or	
Electronic	2
Beaker, 100 mL	12
Beaker, 250 mL	12
Black Box (set of 24)	1
Bottle, Plastic, 500 mL (fuel)	2
Bottle, Plastic, 500 mL (soft drink with clear bottom)	12
Bottle, Plastic, 2 L (soft drink)	12
Brush, Nylon, Test-tube	12
Bucket, Plastic, 5 qt	2
Burner Stand	12
Cloud Chamber Set	1
Conservation of Mass Kit	12
Container, Plastic	12
Corks, No. 7, Slotted for Thermometer	24
Crucible, Size 00, Porcelain	12
Cylinder, Graduated, 10 mL	12
Cylinder, Graduated, 50 mL	12
Dice, Common Game Size	144
Dish, Size 000, Evaporating, Porcelain	12
Electrodes, Copper, 20-mesh, 2 in. × 4 in.	2
Electrodes, Zinc, 1.5 in. × 4 in. × 0.02 in.	2
Electrolysis Electrodes (stainless steel)	12 pairs
Fasteners and Rings (1 pkg.)	12
Funnel, Plastic, 65 mm × 65 mm	12
Geiger Counter	1
Gram Mass Set, 50 g × 100 g	1
Hammer	1
High-Voltage Source	1
Light Bulb, Incandescent	1
Magnifiers, Hand, 5X	12

ITEM	NO.NEEDED
Mass of Atoms Film (VHS or DVD)	1
Metal Cube, Cylinder, and Slab Set	12
Microburners	12
or	
Alcohol Burners	24
Molecular Size and Mass Kit	1
Mortar and Pestle Set	1
Peg Board Kit	12
Power Supply, 6–12 V (instead of 6-V cells)	12
Rack, Test-tube	12
Safety Glasses	24
Scoopula, Stainless Steel, 7 in.	12
Spectral Analysis Kit (Flame Test Kit)	1
Spectrum Tubes	Assorted
Stirring Rods, Glass, 5 mm × 150 mm	12
Stoppers, Rubber, No. 2, Solid	36
Stoppers, Rubber, No. 2, 1 Hole, Safety	24
Stoppers, Rubber, No. 4, 1 Hole, Safety	12
Stoppers, Rubber, No. 4, 2 Hole, Safety	12
Test Tube, 20 mm × 150 mm, Heat Res. Glass	72
Test Tube, 25 mm × 150 mm, Heat Res. Glass	72
Thermometer, 76 mm Immersion, 20°–100°C	24
Tray, Plastic, Black Finish, 40 cm diameter	12
Triangle, Wire, 2-in. Pipe Stem	12
Tubing, Black Rubber, $^3/_{16}$ I.D., $^3/_8$ O.D.	36 ft
Tubing, 6 mm, Heat Res. Glass, Straight	12
Tubing, 6 mm, Heat Res. Glass, Rt. Angle, Short & Long	12
Tubing, 6 mm, Heat Res. Glass, Rt. Angle, Both Short	12
Vacuum Cleaner (canister type)	1
Wire Leads with Alligator Clips	24

List of Chemicals and Consumables

ITEM	USED IN CHAPTER									
	1	2	3	4	5	6	7	8	9	10
Alcohol, Denatured, Ethanol 95%, 1 gal	×	×	×	×	×	×				
Alcohol, Isopropanol, USP 99%, 1 pt			×	×	×					
Alka-Seltzer, 4 dozen tablets		×	×	×						
Aluminum foil, Heavy, 1 roll									×	
Aluminum foil, Regular, 1 roll							×		×	
Baking Soda, 1-lb package	×			×						
Batteries, 6 V (24)						×				
Boiling Chips			×		×					
Citric Acid, Granular, Hydrous, USP, 100 g				×						
Copper Dust, Purified Electrolytic, 100 g						×				
Copper Strips or Electrodes, 1 pkg.										×
Copper, Fine Gran., Reagent, 100 g		×								
Copper(II) Acetate Monohydrate, Reagent, 150 g				×						
Epsom Salt (Magnesium Sulfate) USP, 100 g			×							
Filter Paper, Whatman #1,Tape 2 cm,1 roll					×					
Filter Paper, Whatman #1, 12.5 cm, box of 100					×					
Glycerine (Glycerol) USP, 1pt	×		×		×	×				
Hydrochloric Acid, Conc. Reagent, 1 pt						×				
4-(tert-octyl)phenol (TOP), 600 g			×	×						
Pens, felt tip, green, red, black (BIC brand)					×					
2,6-Di-tert-butyl-4-methylphenol (BHT),150 g			×							
Potassium Nitrate, Granular, USP, 0.5 kg				×						
Potassium Dichromate, Granular, USP, 150 g				×						
Sand, Washed, 1 kg	×									
Sodium Carbonate, Monohydrate, USP, 1 kg						×				
Sodium Chloride, Fine, USP, 0.5 kg		×		×	×					
Sodium Nitrate, Gran., Purified, 100 g				×	×					
Sugar, Granulated, 0.5 kg				×	×					
Sulfur, Powder, USP 0.5 kg		×			×					
Tea	×									
Wood Splints, approx. 12 cm long						×				
Zinc, Commercial, 0.05 cm × 1 cm × 1 cm, 100 squares						×				
Zine Iodide, 98%, 50 g										×

1 Volume and Mass

NOTES

GENERAL COMMENTS

As you introduce a new class to *IPS*, try to set the tone for the entire year on the first day. The short note "To the Student" (on page x in the text) and Experiment 1.1, Heating Baking Soda, will help you do that.

The purpose of the note is to alert students to the interplay of the three forms of active learning in the course: experimenting, reading, and solving problems. You may want to read the note in class either before or after Experiment 1.1.

The purpose of the experiment is to raise questions, some of which will be answered later in this chapter. It also provides the first steps in developing laboratory skills.

Raising the question of how to compare amounts of solids, liquids, and gases at the end of Experiment 1.1 serves as a motivation for the study of volume and mass. We begin with volume, showing different methods of measuring it and the need to say precisely what we mean by the volume of an object. After pointing out the shortcomings of volume as a measure of the quantity of matter, we then proceed to mass, which is operationally defined as that property of matter that is measured with an equal-arm balance. However, in practice, the course no longer requires the use of the equal-arm balance.

Determining the sensitivity of a balance (Experiment 1.8) has been written so that it can be done with equal-arm balances, unequal-arm balances, or electronic balances.

SUGGESTED SCHEDULE

Section 1: one experiment	2 periods
Sections 2–4: one experiment	4 periods
Sections 5–7: no experiments	2 periods
Section 8: one experiment	2 periods
Chapter Test No. 1	2 periods
	TOTAL 12 periods

NOTES

EXPERIMENT

1.1 Heating Baking Soda

Matter can be taken apart in instructive ways that raise questions that serve as a base for further study and experiments. This "curtain-raiser" experiment is an example. You can entice students to think by asking, "Where was the gas before the white solid was heated? How could a colorless liquid be held in a white solid? How is it possible for such a small amount of solid to yield such a large volume of gas?" The purpose of this experiment is not to learn the names of the kinds of matter formed when baking soda is heated, but to recognize the need for a good method for measuring a quantity of matter.

The purpose of the rhetorical questions in the first paragraph of this section is to raise interest in the experiment and show the surprising aspects of the experiment. By no means should these questions be confused with testing a hypothesis.

IN GREATER DEPTH

Is a Hypothesis Needed at the Beginning of Every Experiment?

There is a widespread practice among science teachers to have students write a hypothesis before they begin every experiment, and, at the end of each experiment, to have them conclude whether their hypothesis was true or false. Sometimes the requirement to state a hypothesis takes the form "If such and such is true, then this and that should happen." The reason given for this practice is that scientists do it. While this may be true in some cases, it is rarely the case in physics and chemistry.

Physicists and chemists usually do experiments for one of two reasons: (1) if the experiment applies to a new field of study, it is done to find out how nature behaves, or (2) if a prediction is made based upon a model or theory, an experiment is done to test that prediction.

IPS experiments often begin with a question that students could not possibly answer, so the experiment is done to find out how nature behaves. What useful hypothesis could students be expected to write in their notebooks before they begin heating baking soda? Could students predict that a gas and a condensed liquid would be produced when baking soda is heated? Could students predict the density of the gas in Experiment 3.7? For *IPS* students the *entire course* is new. Therefore, we structure the experiments in the spirit of researchers working in a new field. Thus, forcing students to develop a hypothesis that will be confirmed or refuted at the end of the experiment serves no purpose, no matter in what form the hypothesis is stated.

Regarding the second reason for doing an experiment: After a trend has been observed, asking for a prediction may make sense. For example, in Experiment 2.6 many students may predict that the mass of the container will decrease after the cap has been loosened. Such a prediction is based on the conjecture or hypothesis that mass is conserved in closed containers. Nevertheless, this experiment alone does not prove that the hypothesis is correct, as is explained in detail in Section 2.7. Moreover, students should be cautious about making generalizations, as shown in the discussion of the law of constant proportions (Section 6.5). Requiring that students enter a hypothesis (or guess) into their notebooks trivializes scientific work and reinforces the misconception that every scientific experiment begins with a hypothesis. We suggest that beginning an experiment with an open mind about what the results may be is a much better way.

FOR FORMATIVE ASSESSMENT

5th par.

How could you convince your lab partner that there is more gas in the bottle than there was air in the test tube?

Sec.

Can you identify the liquid droplets that you observed near the top of the test tube? What is your evidence?

The Experiment

This is the first experiment and students are not yet familiar with the equipment. It is useful to take time at the beginning of the course to show students how to use items of equipment. As the course progresses, students will know how to use more and more equipment items safely and correctly, so that experiments can be done in less time.

Demonstrate how to insert a glass tube into a rubber stopper. Rubber stoppers come with small-diameter holes, so that they can be enlarged if needed. More than likely, you will need to enlarge these holes so that glass tubing can be inserted safely. A drill holding a 5/16" bit will enlarge a hole so that 6-mm glass tubing can be inserted safely to give a tight fit. Another option is to order safety stoppers, which require no modification.

Showing students how to safely tighten the nut and bolt in the sleeve of the clamp in order to make the clamp's jaws set tightly against its sleeve (tighten a "floppy clamp") should prevent many problems. Note that the small clamp has the longer sleeve, so that it holds objects the same distance from the pegboard as does the large clamp. If the small clamp does not grasp the small test tube securely, press together the U–bend at the rear of each jaw with a pair of pliers to bring both jaws closer together. Never hold a small test tube with a large clamp or a large test tube with a small clamp, because both arrangements are very unstable and may lead to accidents.

Students are advised to use an amount of baking soda that stands 0.5 cm high in a test tube because this is the simplest way to specify the amount. If students cannot estimate a height of 0.5 cm, tell them that it is about the thickness of a pencil. There is no need to teach a lesson on the metric system. Do not make an issue of the amount of baking soda, because it is not very important. The recommended amount will produce about 150 cm^3 of gas and noticeable droplets at the top of the test tube. Twice as much baking soda will double the amount of gas and the number of droplets, but requires a longer heating time.

Be sure to remind students to remove the tubing from the bottles before turning off their burners. Leaving the tube submerged in the container of water will defeat the purpose of this procedure; the end of the tube must be left open to the air so that no water is pushed back into the hot test tube as it cools.

Studying Figure 1.4 is worthwhile. It introduces the idea of a controlled experiment, answering the question, "Is the gas in the collecting bottle really due to the baking soda, or just due to the heating of the air in the test tube?"

A single tea bag will produce enough tea to supply an entire class. If you prefer, either you or a student can bring the tea from home in a plastic (unbreakable) bottle. Baking soda will cause little change in the color of tea, but the white solid left after heating baking soda will turn the tea a darker color. This change in shade will be more apparent if students look into the mouths of adjacent tubes against a white background. Of course, the test tubes must be alike and hold the same volume of liquid.

Answers to Questions

- Nothing appears at the bottom of the test tube, but droplets of a colorless liquid collect near the top of the test tube.
- A gas is collected in the inverted bottle.
- The gas must have come from the baking soda because it does not appear when an empty test tube is heated.
- The droplets came from the baking soda.
- The color of the liquid tea is not the same in the two test tubes after the solids are added.
- The white powder left in the test tube cannot be baking soda because it does not turn tea the same color that baking soda does.

Apparatus and Materials

Pegboard
Small clamp
3 Small test tubes (20 mm × 150 mm)
Scoopula
Alcohol burner and fuel
(or microburner and tubing)
Rubber or plastic tubing (15 in.)
No. 2 one-hole rubber stopper
Right-angle glass bend
(5- or 6-mm tubing)

Plastic container
Collection bottle (1 pint)
Test tube rack
Water
Matches
Baking soda
Glycerine
Tea (250 cm^3 per lab)
Safety glasses
Stirring rod

1.2 Volume

The process of measuring length, volume, or any other quantity consists of counting units. In measuring the length of an object, one counts the number of length units that make up the length of the object. The measurement of volume is introduced in the same manner, by counting the number of unit volumes that will fit in the unknown volume. The text and problems 5 and 30 are designed to develop this method of finding the volume of an object. Only after the basic idea of counting unit volumes is well understood, do we proceed to the formula

$$\text{volume} = \text{length} \times \text{width} \times \text{height}$$

for rectangular solids as a shorthand way of counting cubes. This approach is designed to prevent rote memorization of the formula.

The particular units that are counted are quite arbitrary. Only the metric system is used in this course, and it is introduced slowly. Experience has shown that a gradual introduction without tedious conversion exercises is one of the most effective methods of teaching the metric system. You should insist that all data be recorded and reported in metric units.

It is worthwhile to make sure that your students realize that volume, area, and length are different kinds of quantities (three-, two-, and one-dimensional, respectively) and cannot be compared; for example, 5 cm is not equal to or more or less than 10 cm^2 or 2 cm^3.

Measuring the volume of an irregular object by the displacement of water is an excellent demonstration experiment that will be very helpful in preparing the students for the next experiment.

FOR FORMATIVE ASSESSMENT

3rd par.

Why is counting pennies in a rectangular box not a good way to find the volume of the box?

8th par.

When a liquid sample is poured from a carton into a glass, is its volume changed? Is its shape changed?

Sec.

Why is measuring volume a convenient way to express the amount of a liquid? of an irregularly shaped stone?

1.3 Reading Scales

In some of the experiments to come, the key to valid conclusions will be the reading of a scale to the highest accuracy possible. The purpose of this section is to introduce your students to estimating fractions of a scale division to the nearest tenth. They will apply this skill to reading rulers and graduated cylinders.

NOTES

FOR FORMATIVE ASSESSMENT

Sec.

Report the position of the arrows. (Note: The illustrations for this question appear on page XX at the back of this *Guide*. You may use these masters to make transparencies for projection.)

EXPERIMENT

1.4 Measuring Volume by Displacement of Water

To measure volumes of irregularly shaped objects, students use a graduated cylinder to find the volume of a sample of sand, first when the sand is dry and then by water displacement. The purposes of the experiment are (1) to increase students' understanding of what is meant by volume, (2) to show how it is possible to measure the volume of an irregularly shaped object by displacement of water, and (3) to emphasize that with certain materials, such as sand, we must specify how the volume was measured. Volume has its limitations as a measure for matter, and this experiment will help lay the groundwork for later discussion leading to a consideration of mass as a better measure.

The Experiment

Dry sand with particles in the range of 2 to 4 mm is better than very fine sand, which has a tendency to pack and cause some difficulty when the time comes to remove it. After the dry sand is poured into the dry graduate, tapping the graduate gently will cause the sand to settle slightly. No attempt should be made to pack the sand in any other way; whether or not the sand is well packed is not important.

If the water is added to the sand, and not sand to water as directed in the text, there may be inaccuracies due to air pockets. If dry graduated cylinders are not available for consecutive classes, some grains will adhere to the side of the cylinder, making measurement difficult. This difficulty can be avoided by reserving a number of graduated cylinders to be used exclusively for the measurement of the volume of dry sand, or by carefully drying the cylinder with a paper towel. Wet sand can be removed from a graduated cylinder by repeatedly stirring the sand with added water and pouring off this slush. Putting this slush into the sink can cause expensive plumbing problems, so be sure that you provide a disposal container. An alternative solution is to use small pebbles instead of sand.

If you give each group a different amount of sand, the class will be able to conclude whether the fraction of air space in the sand depends on the amount of sand used. This technique of assigning different amounts of material to each group will be used repeatedly throughout the course.

For the demonstration shown in Figure 1.11, you will need rock salt, a large test tube, a no. 4 one-hole rubber stopper, and a long, straight glass tube with 6-mm outside diameter. Be sure to fire-polish both ends of the glass tube to remove sharp edges. Setting up this demonstration is a good student project. To dissolve the rock salt readily, use recently boiled water that has cooled to room temperature.

Sample Data and Answers to Questions

The results given below are typical:

Volume of dry san	36.0 cm^3
Volume of water placed in the graduated cylinder	18.3 cm^3
Volume of sand plus water	39.4 cm^3
Volume of sand alone, measured by water displacement	39.4 cm^3 – 18.3 cm^3 = 21.1 cm^3
Volume of air space in 36.0 cm^3 of dry sand	36.0 cm^3 – 21.1 cm^3 = 14.9 cm^3
Fraction of air space in the sand	14.9 cm^3/36.0 cm^3 = 0.41 or 41%

Apparatus and Materials

Graduated cylinder (50 mL)
Sand, dry (about 40 cm^3)
Beaker (250 mL)
Water
Several buckets or other containers for collecting the wet sand

1.5 Mass: The Equal-Arm Balance

Even if you do not have your students use the equal-arm balance, we highly recommend that you treat this section thoroughly because it introduces the operational definition of mass. Having an equal-arm balance in front of the class will be helpful.

There is a great deal of confusion about the meanings of mass and weight, but a lengthy discussion cannot be justified here. The course does not need it, and students are not prepared for such a discussion. You, however, should keep in mind the difference between the two.

The weight of an object on Earth is a measure of the force pulling that object toward Earth. Weight can be measured by hanging an object on a spring. The greater the object's weight, the more it will stretch the spring. On the moon, weight is a measure of the moon's pull. Objects weigh one-sixth as much on the moon as they do on Earth.

The quantity measured with an equal-arm balance is mass. The mass of an object is the same everywhere—on Earth, on the moon, or in space. At any specific location, the weight of an object is proportional to its mass. A balance can be used to measure either quantity, because, at the same place, objects of equal mass have equal weight.

Both the equal-arm and unequal-arm (or "single-pan") balances measure an object's mass by comparing it to known or standard masses suspended on the opposite beam of the balance. A top-loading (or electronic) balance does not do this. It detects electronically how strongly an object is pulled toward Earth as it rests on the balance's platform. Hence, an electronic balance actually measures an object's weight, not its mass. However, before an electronic balance is used, it is adjusted ("zeroed") to read the correct mass of a standard mass that is placed on its platform. Therefore, the weight of all other masses determined with this zeroed balance will be measured relative to the weight of this standard mass. For this reason, an electronic balance can be used to measure the mass of an object if the balance is properly zeroed and not moved to another location.

The best way to avoid the danger of confusing mass and weight in this course is to use only the term "mass," both as a noun and as a verb.

FOR FORMATIVE ASSESSMENT

1st par.

Individually or with your lab partner, list the shortcomings of volume as a measure of matter. Be prepared to explain your entries.

6th par.

Will five grams of wood balance five grams of feathers?

1.6 Unequal-Arm Balances

The basic principle of an unequal-arm balance is that the distance of a rider of fixed mass from the fulcrum replaces standard masses at a fixed distance from the fulcrum. Thus, although the arms in the modified *IPS* balance in Figures 1.14 and 1.15 are of equal length, the balance acts as an unequal-arm, or single-pan, balance. The rider on this balance is made of lead. The balance shown in Figure 1.13 is really a combination of both types of balances in which very small standard masses are replaced by the rider.

If you do not use the balance shown in Figure 1.17, you may skip this section. Alternatively, if you do not use electronic balances, you may wish to skip the next section.

FOR FORMATIVE ASSESSMENT

2nd par.

What will be the effect of adding a third beam with a still lighter rider to a double-beam balance?

3rd par.

Why does the balance shown in Figure 1.16 not have a third beam and still lighter rider?

1.7 Electronic Balances

Electronic balances of various types are becoming prevalent in instructional laboratories. Read the instructions carefully to become familiar with the type of balance that is in your laboratory. Learn how to zero and calibrate it, and protect the standard mass from chemicals and moisture.

If air currents disturb your electronic balance, covering the balance with a cardboard box will help. Covering the balance with a plastic cover or box when it is not in use will preserve the integrity of the balance. Never leave spilled solids or liquids on the balance.

E X P E R I M E N T

1.8 The Sensitivity of a Balance

Determining the sensitivity of a balance by assigning a "±" to every measurement requires a large sample and sophisticated statistical analysis. There is no need for that in *IPS*. It is enough for students to develop a feel for the reliability of their measurements. The results will be used in selecting the size of bins when students construct histograms beginning in the next chapter and throughout the course.

In this experiment students learn how to measure masses to a small fraction of a gram, and to find how reproducible their measurements are and what the sensitivity of their balances is. The experiment is designed to demonstrate the limits of the balance when using the same masses in different massings of light and heavy objects. In addition, students find how much mass they need to add to have the balance respond.

Assign problems 24, 26, and 27 only if your students use the *IPS* balance or the single-pan balance. Assign problem 25 only if your students use the *IPS* balance.

The Experiment

A penny and a rubber stopper are two objects different enough in mass to be used in the experiment. Encourage your students to ignore their previous massings of the same object so that each determination is truly independent.

If you use *IPS* balances and different masses are selected from the mass set to mass the same object, the errors in the standard masses must be considered. Table A gives the tolerances of standard masses conforming to class C standards, which are the masses that should be used with the *IPS* balances. (The mass sets should include only masses from 100 mg to 50 g.)

Mass (g)	Tolerance (g)
50	0.020
20	0.010
10	0.007
5	0.005
2	0.003
1	0.002
0.5	0.0015
0.2	0.0007
0.1	0.0005

Table A
Class C Mass Tolerances

Sample Data

1. Mass of a 1993 penny (g):

Massing number	Electronic	Single-pan	*IPS*
1	2.52	2.463	2.510
2	2.51	2.447	2.501
3	2.51	2.464	2.504
4	2.51	2.483	2.502
5	2.51	2.488	2.501

Notice that there are systematic differences between the measurements of any two balances. Such differences also may appear between balances of the same kind.

2. Mass of a #4 rubber stopper (g):

Massing number	Electronic	Single-pan	*IPS*
1	14.57	14.516	14.444
2	14.57	14.478	14.440
3	14.57	14.471	14.440
4	14.56	14.510	14.445
5	14.57	14.500	14.443

The table below shows the results of adding groups of 10 small squares, one at a time, to balances holding a penny. Each group of squares had a mass of 0.0048 g. "Y" indicates that the balance responded and "N" indicates no response.

	Number of squares added to the balanced penny									
Balance	1	2	3	4	5	6	7	8	9	10
Electronic	Y	N	N	Y	Y	N	Y	N	Y	N
Single-pan	N	Y	N	N	Y	N	N	N	Y	N
IPS equal-arm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

These results show that electronic and single-pan balances are not consistently sensitive to 0.005 g of mass, but the *IPS* balance is sensitive to this mass. Electronic and single-pan balances have a sensitivity between 0.005 g and 0.01 g, but the sensitivity of the IPS balance is less than 0.005 g.

Answers to Questions

- For the electronic balance, all the measurements were reproducible only to the nearest 0.01 g. Anything less than that cannot be read on the display.

  On the single-pan balance, one can estimate the position of the rider to the nearest tenth of a division. Thus, the reading can be reported to the nearest 0.001 g. However, the measurements varied within about 0.04 g and are not reproducible to the nearest 0.01 g.

  On the *IPS* balance, the results varied within 0.009 g for the penny and within 0.005 g for the stopper. Note, however, that except for the first measurement of the penny, the data clustered within 0.004 g. When a measurement is clearly outside the range of all the others, it was probably caused by human error and can be ignored. In conclusion, on the *IPS* balance the measurements are reproducible to within 0.005 g.

- Different types of graph paper will have different masses for 400 of its smallest squares. A mass between 0.2 g and 0.8 g is common.

- •One piece of graph paper (about 25 cm^2) with 400 small squares had a mass of 0.19 g, which was 0.00048 g/square or 0.0048 g/(10 squares). Another sheet (about 100 cm^2) with 400 small squares had a mass of 0.82 g, which was 0.0021 g/square or 0.0042 g/(2 squares).

- Answers will vary depending on the graph paper and the type of balance used. For the graph paper with 0.0048 g per group, the results are shown in the table above for the number of squares added to the balanced penny.

  On the average, the electronic balance responded to every second group, which is consistent with a sensitivity of 0.01 g.

  On the average, the single-pan balance responded to every third group.

  The *IPS* balance responded to every group.

- Responding on the average to every second group, the electronic balance shows a sensitivity of 2 × 0.0048 g, or about 0.001 g.

  Responding on the average to every third group, the single-pan balance shows a sensitivity of 3 × 0.0048 g, or about 0.0015 g.

  Responding to every group, the *IPS* balance shows a sensitivity of 0.0048 g, or about 0.005 g.

Apparatus and Materials

Equal-arm, single-pan, or electronic balance
Set of class C gram masses for equal-arm balance only
Rubber stopper
Penny
Graph paper
Scissors

NOTES

ANSWERS TO PROBLEMS

The table below classifies problems according to their estimated level of difficulty and the sections they relate to. In addition to the questions listed in the bottom row (RAEs), there may be others that you will want to extend into lab or home experiments.

SECTION	EASY	MEDIUM	HARD
1	2	1	
2	3, 4, 5, 6	7	
3		8, 9, 10, 11	12
4	13, 14, 15	16, 17	
5	18, 19, 20	21	
6–7		22	
8	24, 26		23, 25, 27, 28
RAEs	32, 35, 38, 39, 41	29, 31, 33, 34 36, 40	30, 37

1. **Why do you think baking soda is used in baking?**
   Heating baking soda produces a gas that causes cake or bread to expand or rise during baking.

2. **List some tools that you have used**

   a. to extend your vision to see distant objects.

   b. to extend your vision to see very small objects.

   c. to tell how hot something is.
   a. binoculars and telescope
   b. microscope and magnifying lens
   c. thermometers

3. **How many cubic centimeters of water are required to fill a graduated cylinder to the 50.0 mL mark?**
   50.0 cubic centimeters.

4. **Rectangular box A has a greater volume but shorter length than rectangular box B. How is this possible?**
   The width and/or height dimensions of box A must be greater than those for box B.

5. **A student has a large number of cubes that measure 1 cm along an edge. (If you find it helpful, use a drawing or a set of cubes to answer the following questions.)**