Introductory Physical Science

9th Edition

Teacher's Guide

AND RESOURCE BOOK

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Introductory Physical Science
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PREFACE
TO THE NINTH 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 *Introductory Physical Science* (*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*.

This edition contains six new chapters. It is highly unlikely that you will be able to complete all 16 chapters. The purpose of the extended contents is to provide you with options, each of which still provides a well-structured storyline. Examples will be discussed in the Introduction.

In addition to the Comprehension Guide Questions™ in the margin of the student text, which are new to this edition, the *Guide* continues to provide questions for formative assessment, primarily for reading sections, that will help you assess student understanding in real time. These are questions that you may wish to ask the class while reading or discussing a given section.

In response to positive feedback, we have added more brief articles labeled "In Greater Depth," which were introduced in the Eighth Edition.

Also in response to suggestions from teachers, this edition of the *Teacher's Guide and Resource Book* includes a CD that contains masters for the duplication of graphic material. This replaces the limited selection of black-line masters that appeared at the end of previous editions of the *Guide*.

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.

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Peter Gendel
H. Graden Kirksey
Harold A. Pratt
Robert D. Stair

AN 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 guidelines that follow in the remainder of this Introduction.

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 sequencing of the program, 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 experiences.

GIVING 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 each 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 that students are better served by studying even a part of the course thoroughly rather than rushing through all of it. This is not to say that you must dwell on the early chapters until the entire class has full mastery of all topics, because all these topics will appear again later in the course. Students have different learning curves; some students who had difficulties at the beginning will catch up later. This fact has been established beyond doubt in *IPS* classes over several decades.

To be able to make good use of the options offered in this edition, you will do well not to avoid adding extraneous material to the course. The For Review, Applications, and Extensions problems at the end of each chapter (RAEs) provide a substantial variety of topics and difficulty levels that will enable you to tweak the course to meet the interests and needs of your students.

The Story Line of the Course

As in earlier editions, the central theme of the course is the study of matter, leading to the development of the atomic model. In past editions, this was done without bringing up the question of energy changes that took place in some of the student experiments. In this edition, we offer the option of studying such changes, including the study of forces and Newton's laws of motion. Thus, the Ninth Edition of *IPS* is divided into three parts:

Part 1 – Properties of Matter (Chapters 1–6)

Part 2 – Atoms and Molecules (Chapters 7–11)

Part 3 – Energy and Forces (Chapters 12–16).

The branching flow of topics in the three parts is outlined in Figure I. Parts 2 and 3 are independent of each other, but the chapters within each part are sequential. This means that you can proceed with either Part 2 or Part 3 after completing Part 1—covering Chapters 1 through 11, or Chapters 1 through 6 followed by 12 through 16.

The flexibility created by this structure also allows for other possible sequences, as illustrated in Figures II–IV. While many other combinations are possible, it is important to remember the sequential development within each branch. For example, attempting to teach Chapter 11 before Chapter 9 would not be appropriate.

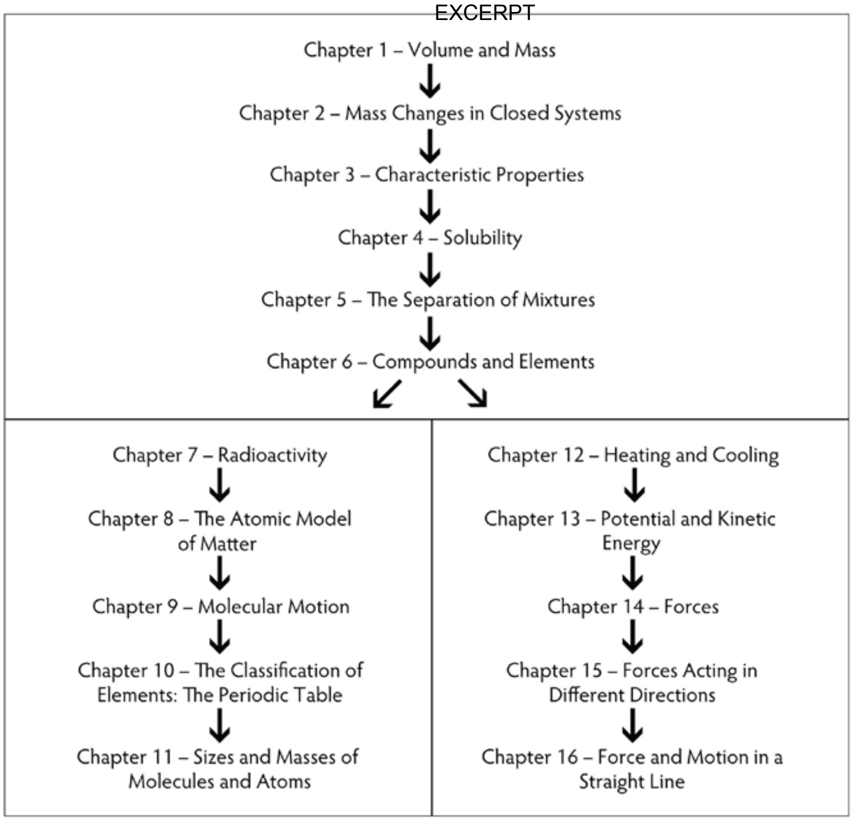

Figure I

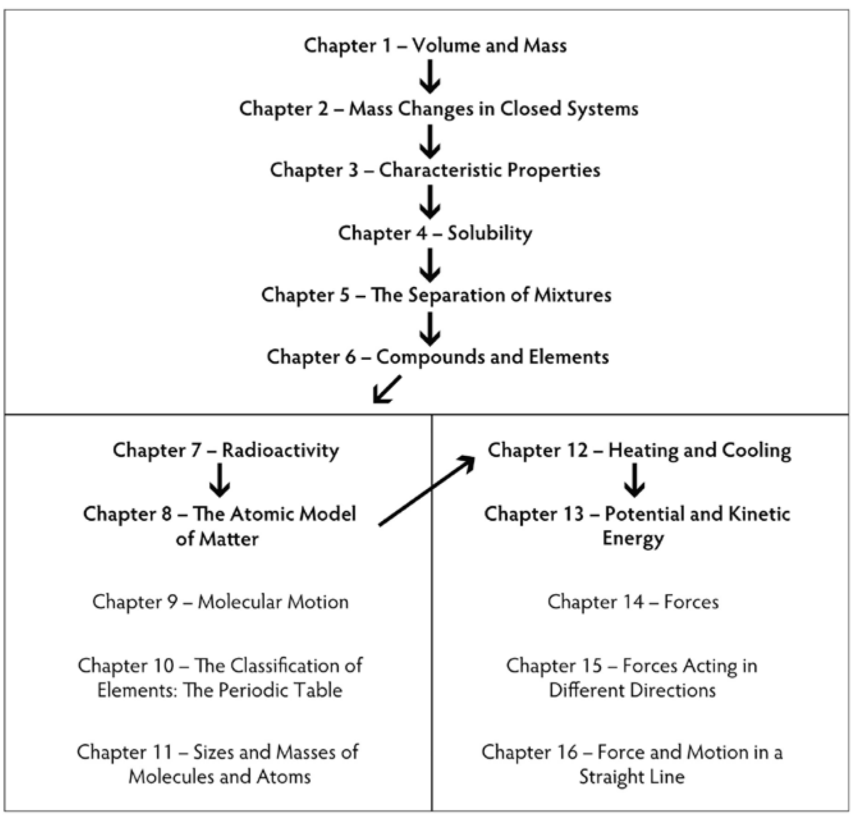

Figure II

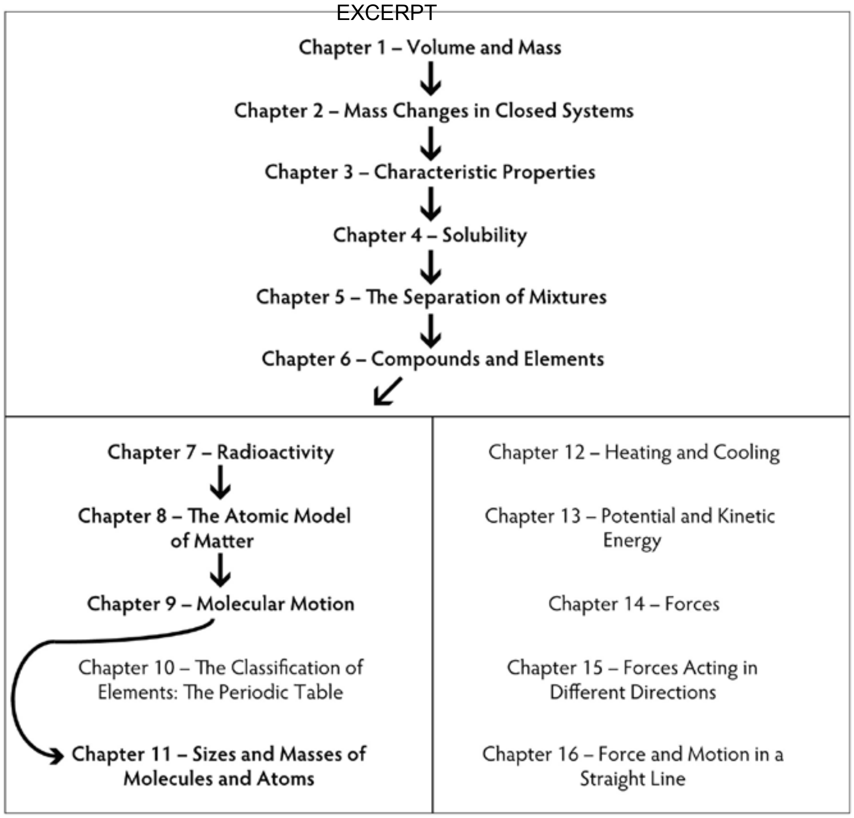

Figure III

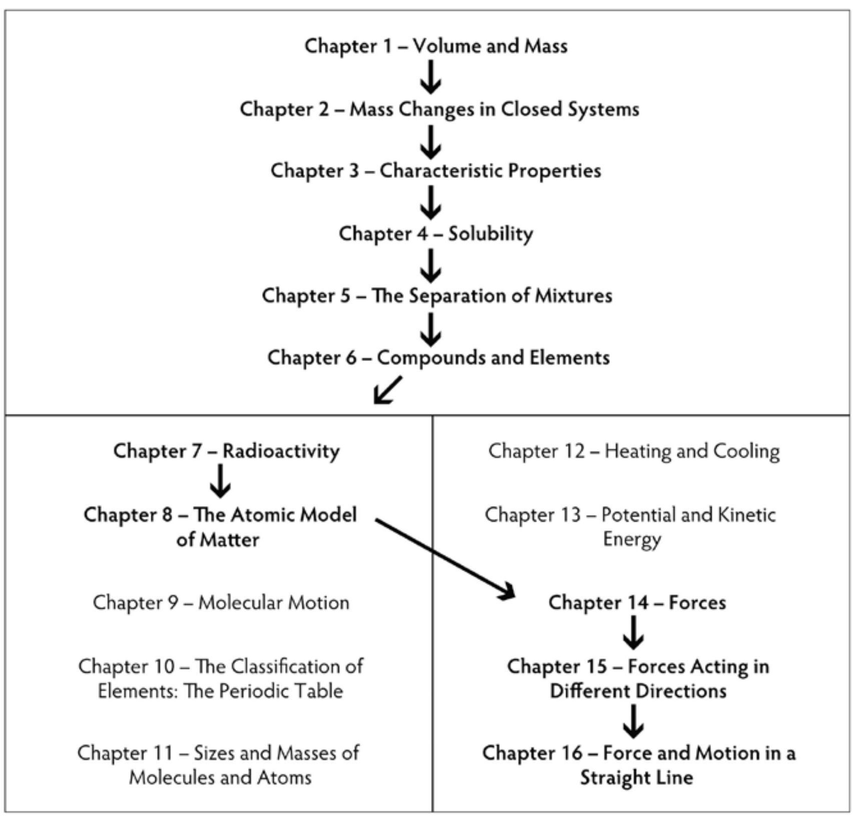

Figure IV

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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	This chapter is of prime importance. Interwoven are two objectives: the development of skills related to the balance and 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 these objectives. Do not expect students to be proficient at using the balance and drawing histograms after the first experiment. However, should the results be so scattered that honest conclusions cannot be drawn from them, do not hesitate to have the class repeat the experi-

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	ment. On the other hand, even the best data does not warrant drawing conclusions about the conservation of mass before students have first-hand experience with the variety of reactions presented in this chapter. 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 students know how to construct histograms by hand, we recommend that they use KaleidaGraph software to save time and explore various choices available to them. A comparison of the absolute changes in mass is quite acceptable in these experiments because all students use about the same mass. Do not overwhelm your students with statistical calculations such as relative change, mean deviation, and so on. With a mathematically strong class, you may wish to introduce fractional change (percent change) in Experiment 2.4, The Mass of Ice and Water, because the mass of the piece of ice may vary substantially from student to student. In other classes, you will do best not to raise the question at all. At first, your students will have some difficulty in making the distinction between uncertainty in measurements and a change in mass. Do not try to make them think there is no change in mass if their data indicates that there is. If a histogram gives so wide a spread of results that no valid conclusion can be drawn, you may wish to have your class repeat the experiment after a class discussion of possible sources of error, and draw a histogram of the new results. Emphasize to students that a single experiment, involving only one kind of change (such as dissolving salt), is not convincing evidence for concluding that mass does not change when other kinds of 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.

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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 a Solid 3.6 Experiment: The Density of a Liquid 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 Distinguishing 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. But lead and iron are not objects; they are substances. 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 differentiating substances from each other and separating mixtures. We concentrate on density, freezing point, and boiling point in this chapter, and on solubility in Chapter 4. Significant digits are introduced in Section 3.4 immediately after Experiment 3.3 where they first appear. They communicate the uncertainty of measurements, but refrain from making them an issue with students. Refer students to the Appendix 1 if they need help.
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 Global Warming 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 dissolved substances.

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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 Mixture Involving Gases 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 whose properties are not changed by use of those methods employed to separate mixtures, they will have learned their lesson.
Chapter 6 Compounds and Elements 6.1 Decomposing Pure Substances 6.2 Experiment: The Decomposition of Water 6.3 The Synthesis of Water 6.4 Experiment: The Synthesis of Zinc Chloride 6.5 The Law of Constant Proportions 6.6 Experiment: A Reaction with Copper 6.7 Experiment: The Separation of a Mixture of Copper Oxide and Copper 6.8 Complete and Incomplete Reactions 6.9 Experiment: Precipitating Copper 6.10 Elements 6.11 Elements near the Surface of the Earth	The aim of this chapter is to show that pure substances can be decomposed by applying intense heat or an electric current. Conversely, pure substances (compounds) can also be synthesized from other pure substances, but only by reacting them in definite mass proportions. After recalling the decomposition of two pure substances, mercuric oxide and baking soda, by heating, electrolysis is used to decompose water (Experiment 6.2) New pure substances are produced that are quite different from the original substance. We then look at the reverse process 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 substances in definite mass proportions (Sections 6.3–6.5). Early difficulties in formulating the law of constant proportions sprang 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. This investigation leads to an understanding of complete and incomplete reactions.

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	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 several substances and was then recovered, suggesting that the copper was there in each of them. The section leads to the operational definition of elements (Section 6.10). The reasoning used in the definition of an element is reinforced with two historical examples. Section 6.11 balances the preceding discussion of scientific methodology with a discussion of the abundance of elements near the surface of the earth.
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. After learning how elements survive in the formation of compounds, students 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 formulating 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 using only the knowledge students have gained in this course (Chapter 11). In addition, it should be noted that radioactivity is largely ignored in the science curriculum. Learning about radioactivity in *IPS* may be their only chance to do so for many students. 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

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	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 this chapter 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.
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 Constant Proportions and the Atomic Model 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 11. 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 these spectra present properties of individual atoms rather than properties of elements in bulk. Finally, the atomic model is used to predict the existence of a half-life for radioactive elements.

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Chapter 9 Molecular Motion 9.1 Molecular Motion and Diffusion 9.2 Number of Molecules and Pressure of a Gas 9.3 A Prediction About the Relation Between Volume and Pressure of Gases 9.4 The Compressibility of Gases 9.5 Temperature and Molecular Speed 9.6 Avogadro's Law 9.7 Masses of Atoms and Molecules 9.8 Behavior of Gases at High Pressure	Until now, we have considered molecules as stationary clusters of atoms. But it is clear that no reaction can take place without atoms moving. In this chapter, we expand the atomic model by adding the motion of atoms and molecules. All gases have some properties that are similar and are due to their molecular motion alone, such as their compressibility. These properties do not depend on the composition of the gaseous molecules. By using a mechanical analogue to a real gas, and some simple reasoning, we can learn how molecular motion can account for the compressibility of gases (Section 9.2). On the basis of this knowledge, we can make a prediction about the relation between the volume and the pressure of a gas (Section 9.3). This prediction is verified by an experiment described in the text, and we are able to state Boyle's law as a consequence (Section 9.4). The mechanical analogue to a real gas also guides us into a qualitative discussion of the relation between temperature and molecular speeds in gases (Section 9.5). The similarity in the behavior of gases is at the root of one of the great developments in nineteen-century physical science, namely Avogadro's hypothesis, and the resulting way to determine molecular and atomic masses (Section 9.6 and 9.7). If this is as far as you can get in the school year, these sections provide both new material and a review of much that has been learned during the year. Finally, there is a word of caution. The conclusions reached in the last sections are valid if Boyle's law is valid. However, Boyle's law, like other laws, is valid only over a limited range of conditions (Section 9.8).
Chapter 10 The Classification of Elements: The Periodic Table 10.1 A Historical Sketch 10.2 Some Families of Elements 10.3 Activity: Atomic Mass and Other Properties of Atoms	Enabling students to make sense of the periodic table of the elements before they take a course in chemistry is a tall order. The usual approach of classifying elements by the electronic configurations of their atoms does not work. Therefore, we opted for an historical approach that builds on what students have learned in Chapters 6, 8, and 9. This allows us to present the development of the peri-

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	odic table as a model that made the organization of known facts possible and made predictions that were found to be correct. But even our approach comes at a price: The density of factual information and terms is by far higher here than in any other chapter in this book. This is especially true in Sections 10.2, 10.4, and 10.6. Therefore, the pilot teachers strongly recommended letting students take the chapter test as an open-book test (something that we recommend in general). We begin with a historical sketch that puts the discovery of elements through the middle of the nineteenth century on a time scale (Section 10.1). To remember the properties of so many elements, a classification system is useful (Section 10.2). Although each element has its unique set of properties, elements can be classified into separate groups, or families, because members of each family have particular properties that are either similar or identical. The properties used to classify elements are those studied earlier in the course. With no student experiments in this chapter, the demonstration suggested for this section is very convincing. Students perform an activity with a set of 24 specially prepared cards (Section 10.3). Cards resemble an element's entry displayed in the periodic table. These cards are arranged to understand how the classification of the elements led to the periodic table, and that classifying elements into families is a matter of judgment. This activity has historical connotations in that it raises the question of the order of potassium and argon. The activity is briefly extended in Section 10.5 to show the need for additional columns in the periodic table. The chapter ends with use of the periodic table as a scientific model by showing how Mendeleev predicted the properties of germanium before this element was discovered (Section 10.6). If it is close to the end of the school year and you do not have time for both Chapters 10 and 11, you can choose either, because this chapter is not a prerequisite for Chapter 11.

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Chapter 11 The Sizes and Masses of Molecules and Atoms 11.1 The Thickness of a Thin Layer 11.2 Experiment: The Thickness of a Thin Sheet of Metal 11.3 Experiment: The Size and Mass of an Oleic Acid Molecule 11.4 The Mass of Helium Atoms 11.5 The Mass of Polonium Atoms	This chapter connects directly with Chapter 9, in which we found atomic and molecular masses in unified atomic mass units. The main purpose of this chapter is to find the connection between the atomic mass unit and the gram. We arrive at our goal in stages. First, the thickness of a thin foil is measured with a meter stick (Experiment 11.2). An analogous experiment follows to measure the thickness of a thin film of oleic acid, which is quite small. The thickness of this film represents an upper limit of the size of an oleic acid molecule. Sections 11.4 and 11.5 run parallel to the film "The Mass of Atoms." Here the absolute mass of atoms is measured, whereas Chapter 9 addressed the measurement of their relative masses only.
Chapter 12 Heating and Cooling 12.1 Introduction 12.2 Experiment: Mixing Warm and Cool Water 12.3 A Unit of Energy: The Joule 12.4 Experiment: Cooling a Warm Solid in Cool Water 12.5 Specific Heats of Different Substances 12.6 Experiment: Melting Ice 12.7 Heat of Fusion and Heat of Vaporization 12.8 Experiment: Heat of Reaction 12.9 Comparing the Energies Involved in Different Reactions	Chapters 12 and 13 deal with forms of energy and their transformations. Usually, the study of these topics is preceded by the study of forces, often including Newton's three laws. This is then followed by the introduction of kinetic and potential energy, leading (sometimes) to forms of energy associated with changes in temperature or phase. In contrast, here we build on your students' prior experience in the *IPS* course. They have heated and cooled substances on many occasions, beginning with Experiment 1.1, Heating Baking Soda. They have also noted temperature changes associated with dissolving (Experiment 4.1, Dissolving a Solid in Water) and the formation of substances (Experiment 6.4, The Synthesis of Zinc Chloride). Our study begins with by associating energy changes with temperature changes. Equal and different masses of warm and cool water are mixed in Experiment 12.2 to clarify the difference between changes in temperature and changes in thermal energy. From this experiment, a unit of energy—the joule—is defined (Section 12.3). Next different substances at different temperatures are mixed (Experiment 12.4), leading to specific heat as a characteristic property (Section 12.5)

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	and establishing that temperature change alone is not a measure of energy. Energy changes associated with melting and vaporization are studied where no change in temperature occurs. Finally, students are shown that energy can be released when two substances react, which introduces the study of potential and kinetic energy in Chapter 13.
Chapter 13 Potential Energy and Kinetic Energy 13.1 Experiment: Heating Produced by a Slowly Falling Object 13.2 Gravitational Potential Energy 13.3 Kinetic Energy 13.4 Kinetic Energy as a Function of Speed 13.5 Experiment: Changing Gravitational Potential Energy to Kinetic Energy 13.6 The Law of Conservation of Energy	We now continue the investigation of phenomena that occur simultaneously with a change in temperature. Gravitational potential energy is introduced by using a slowly falling weight to raise the temperature of an aluminum cylinder (Experiment 13.1). The temperature rise of the cylinder is found to be proportional to the weight of the falling body for a fixed falling distance. The increase in thermal energy of the cylinder is then related to the falling distance in Section 13.2. The proportionality constant that relates the change in gravitational potential energy to the product of the falling mass and the falling distance is developed. The result obtained here is generalized in an end-of-chapter problem to show that the change in gravitational potential energy depends only on the change in vertical height and not on the distance traveled along an incline. Kinetic energy changes are studied by use of a spinning wheel having a heavy rim. The increase in temperature generated by stopping this wheel is described in detail, leading to the development of the definition of kinetic energy (Sections 13.3 and 13.4). After changes in both gravitational potential energy and kinetic energy can be calculated, their conversion is studied in Experiment 13.5. The loss in gravitational potential energy of a falling mass is used to spin a wheel initially at rest. The resulting loss in gravitational potential energy of the falling mass is compared to the gain in kinetic energy of the spinning wheel. The chapter ends with a discussion of the law of conservation of energy.

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Chapter 14 Forces 14.1 Introduction 14.2 Weight: The Gravitational Force 14.3 Activity: The Elastic Force: Hooke's Law 14.4 Experiment: The Magnetic Force 14.5 Experiment: Sliding Friction 14.6 Friction and Weight 14.7 Newton's Third Law	The first three paragraphs of the text connect this chapter to Chapter 13; changes in gravitational potential energy and kinetic energy are associated with forces. Changes in thermal energy can be associated with the force of friction. Therefore, the study of some common forces is a natural continuation of Chapters 12 and 13. Extensive use is made of proportions in this chapter. If you think that this topic may need some review or reinforcement, we suggest that you incorporate the study of Appendix 1 into your schedule. Although "force" is a common word, its use in science is made clear in the Introduction. It also notes that there are forces, like gravity, that act on objects without touching them. The proportionality between an object's mass and the gravitational force acting on that mass (its weight) is addressed in Section 14.2, and the proportionality constant at the earth's surface, 9.8 N/kg, is introduced. Although students are familiar with the measurement of mass, Experiment 14.3 introduces the use of a spring scale to measure weight. Students measure the stretch of a spring as a function of the weight suspended from it and find a relation between the two (Hooke's law). Like gravity, the magnetic force acts on an object without direct contact. But unlike gravity, the change in the strength of the magnetic force changes dramatically over short distances. This change in strength of the magnetic force is measured as a function of the distance of separation of two magnets in Experiment 14.4. In recognition of the prominent role that the force of friction plays in daily life, friction does not act on an object at rest unless there is force acting on that object. Students investigate the minimum force needed to keep a body moving under a variety of conditions (Experiment 14.5 and Section 14.6). The results of the experiment coupled with the reading section lead to the conclusion that, in addition to the types of surface in contact, the

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	frictional force depends on weight, not on the area of contact between the surfaces. Finally, Newton's third law is discussed for static situations.
Chapter 15 Potential Energy and Kinetic Energy 15.1 Balanced Forces on a Line 15.2 Representing Forces in a Plane 15.3 Experiment: Balanced Forces in a Plane 15.4 The Net Force 15.5 Forces and Their Components 15.6 Experiment: Forces Acting on Moving Objects 15.7 Newton's First Law	We live in a three-dimensional space. Forces act in different directions, and objects move in various directions, but the forces and movements are not necessarily in the same directions. Ideally, we should study the connection between forces and motion in three dimensions, but this is difficult at the introductory level. Luckily, most of the relations between force and motion can be studied in two dimensions. Indeed, many of the motions around us take place in a single plane. In contrast, restricting force and motion to one dimension—a single straight line—is entirely artificial and has little to do with the real world. It gives students the wrong idea that a force can only speed up or slow down a moving object, leaving out the vector nature of forces and their role in changing the direction of motion of an object. The progression of the chapter can be summarized as follows: Forces along a straight line can be represented by signed numbers—positive in one direction and negative in the opposite direction (Section 15.1). They also add like signed numbers. To describe forces in any direction, we introduce vectors (Section 15.2) and apply this representation in an experiment studying three balanced forces in a plane (Section 15.3). The conclusions from the experiment are then extended to unbalanced forces (Section 15.4). After a brief discussion of the components of forces, students study the qualitative effects of forces on moving objects (Section 15.6). Besides leading the way to Newton's first law (Section 15.7), this experiment is intended to help avoid the notion that objects always move in the direction of the net force acting on them.

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Chapter 16 Force and Motion in a Straight Line 16.1 Experiment: The Motion Detector 16.2 Velocity Graphs 16.3 Experiment: Motion Under a Constant Net Force: The Effect of Time 16.4 Experiment: Motion Under a Constant Net Force: The Effect of the Magnitude of the Force 16.5 Free Fall and the Effect of Mass: A Prediction 16.6 Experiment: Testing a Prediction: The Relation Between Mass and Change in Velocity 16.7 Newton's Second Law	The purpose of this chapter is to give students a rudimentary understanding of Newton's second law. This is a tall order even at the high school level, and it is even more so for eighth- or ninth-grade students. One of the hurdles to arriving at Newton's second law in its common formulation ($F = ma$) is the need to understand acceleration. Unlike velocity, acceleration is not an intuitive quantity, and it takes substantial class time to understand it. Therefore, we decided to present the second law for a constant net force in the form Force • (time interval) = mass • (change in velocity). In this chapter, we consider only changes in velocity along a straight line. Consequently, it is possible to use a motion detector to collect the data that leads to the second law. The payoff of this chapter is in the last section and the RAEs. It is in the final section that the conclusions of the three previous experiments are drawn together into the second law, and some implications of the second law are addressed. Just as students had to learn to use a balance properly, so they have to learn to use a motion detector. Section 16.1 and 16.2 are devoted to this task. The main part of the chapter is devoted to the study of the three factors that affect the change in velocity of an object under the influence of a constant force. Two of them—the time interval the force acts (Experiment 16.3) and the magnitude of the force (Experiment 16.4), are studied in the lab. The third, the dependence on mass, is addressed in Section 16.5, which looks at free fall as a way to reconcile a common misconception about mass and motion. This then leads to a prediction which is tested in Experiment 16.6. Finally, all three factors are brought together in the formulation of Newton's second law (Section 16.7).

Components of the Course

THE PIVOTAL ROLE OF EXPERIMENTS

Our current knowledge of physical science is the result of many years of experimentation. No student can experience all the discoveries that have been made to date, but as far as possible, we think that he or she should 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 posing leading questions, call students' attention to the important points in an experiment. Sometimes the answers to these questions merely require thought; 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 they will 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 more resourceful and confident.

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 through 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 data on a dozen samples of different sizes in one class period. These data 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. This give-and-take atmosphere is vital if students are to learn how knowledge is acquired and how science operates. 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 students, it is of the utmost importance that the specified equipment be on hand and easily accessible. Although a well-designed science classroom is always an asset, this course can be taught successfully in a classroom with one sink, flat tables, and a reasonable amount of storage space.

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

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 to individual work in the laboratory; it forces each 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 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, even while working in pairs, a lab notebook must be kept by each student.

Safety Procedures

Since the best way to deal with accidents is to prevent them from happening in the first place, 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 for those chemicals (pages xxxvii and xl). 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.
- Where possible, utilize plastic or unbreakable containers for dispensing materials.
- Dispense chemicals from several locations in the classroom. This will reduce the crowding and pushing that may 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 from which they obtained them.)
- Do not substitute chemicals in experiments unless you have thoroughly checked the procedure.
- Always use glycerin as a lubricant for inserting glass tubing into rubber stoppers. Towels should be used to protect against cuts due to breakage of tubing.
- Use only micro burners; do NOT use full-size Bunsen burners.
- Always make sure that micro burners are turned off at the source of the gas, NOT at the burner itself.
- If using alcohol burners, 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 one-gallon metal cans. Pint-size plastic bottles should be filled away from any flame (in a storeroom, if possible), 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 appropriate. Also, be sure to wear them yourself whenever they are included in the list of apparatus and materials for an experiment in this *Guide*.
- NEVER allow students to taste anything.

Pre-Lab and Post-Lab Discussions

THE 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 another discussion (a "post-lab") after the completion of the experiment, reviewing it with the class and discussing the conclusions that may be drawn from it.

In the pre-lab discussion, it is advisable to involve 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 related to the experiment.

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, the post-lab discussion is critical. It is in the post-lab that students learn the value of working cooperatively to compile sets of data which can then be analyzed and from which conclusions can be drawn.

CHARACTERISTICS OF THE PRE-LAB DISCUSSION

Raising questions and leading a class discussion are two effective teaching strategies that can be utilized during the pre-lab to help the students understand the experiment and any new techniques required to carry it out. (Sometimes, as in the case of safety precautions, these strategies are not advisable—you must simply tell students how to do something.)

Some experiments, such as 1.8 and 5.6, 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 calculation of results. This is true, for example, of the experiments on conservation of mass in Chapter 2.

In your pre-lab discussion of an experiment, do not give away the expected results. (However, you do not have to pretend, with any class, that the results are not already 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 compilation of data obtained by the entire class. In this way, data can be collected for a range of different conditions in a reasonable amount of time, and richer conclusions can be drawn. Even when all the students do exactly the same experiment, they usually have time to take only one set of readings. Since individual results vary, only the pooling of the results from all lab groups during the post-lab discussion will lead to useful conclusions.

Perhaps the best way to pool individual results is to construct 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. In this *Guide*, examples of class histograms are given in the Sample Data section 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, while others may see the repetition as punishment.

Software for Histograms

As indicated, histograms are used where appropriate throughout the course to display data collected by students. 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 software, such as *KaleidaGraph* from Synergy Software.

KaleidaGraph is a powerful, user-friendly software package 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 bin size and borders, see Sections 2.2 and 2.3 of the student text.) Other advantages of the software include the ability to extend the range of a histogram by adding empty bins and the ability to select from a variety of fonts and colors. Visit our web site 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 notes are written in ink or pencil is not important; the notebook 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 "Purpose," "Apparatus," "Diagram of Apparatus," or "Procedure." This tends to replace considered 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 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—after receiving your approval for their procedure—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 how the calculated figure is obtained, 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, the sequential listing of procedures, data, calculations, and observations 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 LAB 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 an 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.

The blue, bulleted questions posed in each experiment can only be answered during or after the experiment. These questions are not rhetorical; they 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 are usually based on experimental data from the entire class, the full set of class data needed to support those conclusions should be included in the notebook. This will also emphasize the need for having a large body 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 at 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 on subsequent labs.

The Text

DEVELOPING SCIENCE READING SKILLS

The central role of laboratory work notwithstanding, the *IPS* course is much more than a collection of experiments. The sections not marked as Experiments lay the groundwork for new concepts, extend and generalize the results of experiments, 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.

To continue learning throughout their lives, students must develop their reading skills. In particular, for this and subsequent science courses, they need to develop science reading skills. Keep in mind that your incoming students have had little or no prior experience at reading a science textbook. They will need to develop the skills necessary to understand what they read in a science book, and you will need to help them.

This edition of *IPS* provides a new tool for both you and your students. *Comprehension Guide Questions*™ (CGQs) appear in blue boxes in page margins and are related to adjacent text paragraphs. They can be used in a variety of ways to increase students' reading comprehension. As students read independently, the CGQs allow them to self-assess their comprehension of passages they have just read. In class, CGQs can be used to quickly gauge the level of students' reading comprehension.

As they were being tested in pilot schools, the CGQs were used in a variety of ways by pilot teachers, depending on the backgrounds and abilities of their students. Some of the methods utilized included:

- Students were asked to determine the answers to the CGQs as they read passages independently. The teacher then followed up by asking specific students to answer the questions in class.
- Students read a passage or an entire reading section independently in class, and then formed groups of two to four students to discuss the reading and the associated CGQs before participating in a general discussion by the entire class.
- A paragraph was read aloud and, after a brief pause, one or more students (in succession) were asked to answer the CGQ.
- A paragraph was read aloud, and then pairs of students were asked to discuss the CGQ among themselves before the answer was brought up before the entire class. The pairs in some cases consisted of lab partners and in others were students seated next to each other.

While the CGQs will help to improve students' reading comprehension, they are not alone sufficient to significantly develop students' science reading skills. You will need to model good science reading practices. Guide students as they read aloud in class. Remind them to stop when they encounter a reference to a graph or figure, go to the reference, and study it—including any caption—before going on with their reading. In *IPS*, these elements are integral parts of the text, not just eye-catching decorations for marketing purposes. A knowledge and understanding of the figures is necessary to understand the concepts presented in the text.

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 sections within chapters generally cover single concepts and are designed to reinforce ideas immediately after they are encountered in the text or in an experiment.

The sets of problems labeled “For Review, Applications, and Extensions” (RAEs) located at the end of each chapter follow the order of presentation of material within the chapter. The RAEs are designed to extend 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 enrichment assignments for students who wish to extend their understanding.

To derive the maximum benefit from the RAEs, 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 abilities 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 sometimes 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 the 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 of vocabulary by 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.

Formative Assessment

FORMATIVE ASSESSMENT IN INSTRUCTION

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 course goals. Research evidence strongly supports that formative assessment improves students' understanding and achievement.

What is distinctive about formative assessment is its forward look. The usual perspective of most assessments is a backward look at 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. Identification of learning problems and the appropriate modification of instruction are the goals of formative assessment, not the assignment of grades. Assigning points or grades alters the spirit of the activity, the rationale for doing it, the time and effort required on the part of the teacher, and the effectiveness of the learning process.

There is no simple, single recipe for doing formative assessment. It is always going on as teachers listen to students' responses, examine notebooks, mingle with students as they do experiments, grade quizzes, and use other strategies to assess student progress. Perhaps the most direct method is to elicit feedback by asking relevant questions and monitoring student responses. This edition of *IPS* provides a variety of formative assessment questions, using a range of strategies, in the text and the *Teacher's Guide and Resource Book.*

FORMATIVE ASSESSMENT IN *IPS*

There are three distinct sets of formative assessment questions in this edition of *IPS*. One set is found in the *Teachers Guide and Resource Book*; one set, which is color-coded in light yellow, is found at the end of many sections of the text; a third set consists of the Comprehensive Guide Questions (CGQs), also in the text.

The formative assessment questions found in the *Guide* are usually associated with a particular reading section and are designed to determine if students comprehend individual steps in the development of specific ideas. Therefore, most questions are assigned to a particular paragraph in the reading section. If you are reading the section together with the class, use each question after reading the designated paragraph. Questions designated "Section" are more general and best asked immediately upon completion of the pertinent section of the text. The field testing of our formative assessment questions showed that they inspired teachers to develop additional questions on their own.

The formative assessment questions found in this *Guide* can be used to supplement and extend the CGQs in the text. Many of the strategies successfully applied by pilot teachers in using the CGQs (see page xxx) have also shown to be effective in using the formative assessment questions from the *Guide*. One obvious difference is that the guide questions must be read aloud by the teacher.

A third set of formative assessment questions appears color-coded in light yellow at the ends of sections in the text. These questions are designed to assess how well students understand a key point, a prerequisite for subsequent learning, or the reason for doing something. 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 your 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. 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 want 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 to help your students assess their own learning. Self-assessment has been shown to be one of the most effective means of improving student success.

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 subjective indicator is the improvement shown in students' skill at orally communicating 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 PAPER WORK

Your paper work 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 sixteen 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 *Assessment 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 notebook" tests can be used to advantage in this course. Appropriateness for "open book" tests make a good criterion for assessing any question you write.

THE *DIAGNOSTIC ANALYSIS* SOFTWARE

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

ASSIGNING GRADES

This course is definitely not suited to a straight averaging of all grades at the end of a semester or the year. Combining the averages of all *IPS* multiple-choice tests, laboratory tests, essay tests, and the lab notebook grades 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. Consequently, a student who demonstrates understanding later in the course should not be penalized by averaging for incomplete understanding of the same concept earlier in the course. The Epilogue of the student text may help you make a better judgment of your students' achievement.

As mentioned earlier, when you review your students' laboratory notebooks, RAEs solutions, and oral presentations, you should 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 this Introduction that the *IPS* course offers a wide variety of experiences to the individual student 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 prelab and the class begins to work, you can divide your time among students according to their individual needs. Spend less 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 more difficult 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 abilities of the students, the size of the class, and the number and length of class periods. In a large class of below-average students, you may find it profitable to go very slowly, spreading the first eight chapters over the entire year. With a smaller and more talented group, you may find it more challenging to proceed at a greater speed with the first six chapters, going into greater depth in the second half of the course. 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	9	11
2	11	10	8
3	18	11	9
4	13	12	13
5	16	13	11
6	17	14	10
7	(8*)10	15	11
8	14	16	14

* With the minimum amount of experimental work.

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

LIST OF EQUIPMENT

ITEM	NUMBER NEEDED
Air Puck Kit	12
Air puck platform	12
Balance, equal-arm	1
Balance, single-pan or	12
electronic	2
Beaker, 100 mL	12
Beaker, 250 mL	12
Black box (set of 24)	1
Bottle, plastic, 500 mL (for burner fuel)	2
Bottle, plastic, 500 mL (soft drink)	12
Bottle, plastic, 2 L (soft drink)	12
Boyle's Law Apparatus	1
Bromine Tubes Set	1
Brush, nylon, test tube	12
Bubble level (or leveling cell phone app)	1
Burner stand	12
Cart platform	1
Cart superstructure	1
Cart with low-friction bearings	1
C-clamp, 4 – 6″	12
Cloud Chamber Set	1
Conservation of Mass Kit	12
Container, plastic, rectangular (approx. 10″ × 6″ × 4″ deep)	12
Crucible, size 00, porcelain	12
Cylinder, graduated, 10 mL	12
Cylinder, graduated, 50 mL	12
Cylinder set, equal volumes/different masses	12
Dice, common game size	144
Evaporating dish, porcelain, size 000	12
Electrolysis electrodes (stainless steel)	12
Energy wheel kit, with accessories	1

(continued)

ITEM	NUMBER NEEDED
Fasteners and Rings Package	12
Fire syringe	1
Force Kit	12
Frictional Force Apparatus	12
Funnel, plastic, 65 mm × 65 mm	12
Geiger counter or computer-interfaced radiation monitor	1
Gram mass set, 50 g × 100 mg	1
Graphing software (such as *KaleidaGraph*™)	1
Gravitational Potential Energy Kit	12
Hammer	1
High-voltage source (for spectrum tubes)	1
Light bulb, incandescent	1
Low-friction pulley with clamp	1
Magnetic Force Apparatus	12
Mass of Atoms film (VHS or DVD)	1
Metal Cube and Slab Set	12
Meter stick	1
Metric rulers, 30-cm	24
Microburners or	12
Alcohol burners	24
Molecular Motion Model	1
Molecular Size and Mass Kit	1
(with lycopodium powder and oleic acid)	
Motion detector and computer interface	1
Pegboard Kit (with 4 small & 3 large clamps)	12
Power supply, 6 to 12 V or	12
6-V batteries	24
Razor blade, single-edge or X-Acto™ knife	1
Rope (6 m or more in length)	1

(continued)

ITEM	NUMBER NEEDED
Safety glasses	24
Scissors	4
Scoopula, stainless steel	12
Weight set, hooked	1
(10 g, 2 × 20 g, 50 g, 100 g, 2 × 200 g, 500 g, 1000 g)	
Spectral Analysis Kit	1
(15 spectroscopes, nichrome wire, handles, chemicals)	
Spectrum tubes	Assorted
Spring scale, 20-N	36
Spring scale, 5-N	12
Stirring rods, glass, 5 mm × 150 mm	12
Stoppers, rubber, No. 2, Solid	36
Stoppers, rubber, No. 2, 1-hole	48
Stoppers, rubber, No. 4, 1-hole	12
Stoppers, rubber, No. 4, 2-hole	12
Stopwatch	12
Test tube, 20 mm × 150 mm, heat-resistant glass	72
Test tube, 25 mm × 150 mm, heat-resistant glass	72
Test tube rack	12
Thermometer, immersion, high resolution, 10°C to 40°C	12
Thermometer, immersion, standard, –10°C to +110°C	24
Tray, plastic, black, 40 cm diameter	12
Triangle, clay, 2-in. wire pipe stem	12
Tubing, rubber, black, 3/16" I.D., 3/8" O.D.	36 ft
Tubing, glass, right angle bend,	12
6-mm O.D. with approx. 3-cm arms	
Vacuum cleaner	1
Washer, large, 1¾" O.D. × ¾" I.D.	12
Wire leads with alligator clips	24

LIST OF CHEMICALS AND CONSUMABLES

ITEM	CHAPTER USED															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Alcohol, ethanol, denatured, 95%, 1 gal.	×	×	×	×	×	×		×								
Alcohol, isopropanol, USP 99%, 1 pt			×	×	×											
Alka-Seltzer™, 4 dozen tablets		×	×	×												
Aluminum foil, heavy duty, 1 roll							×				×					
Aluminum foil, regular, 1 roll							×				×					
Baking soda, 1-lb pkg	×			×												
Balloons, round															×	
Rubber bands		×				×										
Batteries, 6V (24) (if used instead of power supply)						×			×	×						
Boiling chips			×		×											
Cardboard pieces (10 cm × 10 cm or larger)															×	
Citric acid, granular, hydrous, USP, 100 g				×												
Copper dust, purified electrolytic, 100 g						×										
Copper strips or electrodes, 1 pkg									×							
Copper, fine granules, reagent, 100 g		×														
Copper(II) acetate monohydrate, reagent, 150 g				×												
Eyedropper										×	×					
Epsom salt (magnesium sulfate) USP, 100g			×													

(continued)

ITEM	CHAPTER USED															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fishing line, 30-lb test													×			×
Glycerin (glycerol) USP, 1 pt	×		×		×											
Heat sink compound													×			
Wrapping paper, heavy															×	
Hydrochloric acid, concentrated, reagent, 1 pt						×						×				
Ice cubes												×	×			
Magnesium ribbon												×				
Matches	×	×	×		×	×		×								
Paper, 2-cm tape, chromatographic, Whatman #1, 1 roll					×											
Paper, filter, 12.5 cm, Whatman #1, box of 100					×											
Pens or markers, water-soluble, green, red, black					×								×			
TOP, 4-(tert-octyl) phenol, 250 g			×	×												
BHT, 2,6-di-tert-butyl-4-methyl-phenol, 250 g			×													
Milk bottles, plastic, gallon													×			
Potassium nitrate, granular, USP, 500 g				×												
Potassium dichromate, granular, USP, 150 g				×												
Sand, washed, 1 kg	×															
Bags, plastic, sealable, sandwich size													×			
Sheets, latex, 5 cm × 5 cm, 12 sheets		×														

(continued)

ITEM	CHAPTER USED															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sodium carbonate, monohydrate, USP, 1 kg						×										
Sodium chloride, fine, USP, 500 g		×		×	×											
Sodium nitrate, granular, purified, 100 g				×												
Starch solution										×						
Steel wool, 1 pad										×						
Straws															×	
String or heavy thread												×				
Cups, Styrofoam™												×				
Sugar, granulated, 200g				×	×											
Sulfur, powder, USP, 250 g		×			×											
Tape, masking																×
Tea	×															
Wood splints, approx. 12 cm long						×										
Zinc, commercial, 0.05 cm × 1 cm × 1 cm, 100 squares						×										
Zinc iodide, 98%, 50 g																

1

VOLUME AND MASS

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 xiii 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 toward 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 state 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, and many schools no longer have them. For that reason, other types of balances are also introduced.

The process for determining the sensitivity of a balance has been written (in Experiment 1.8) so that it can be done with equal-arm balances, unequal-arm balance, 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

EXPERIMENT

E

1.1 Heating Baking Soda

Matter can be taken apart in instructive ways that raise questions that serve as a basis 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 emphasis in this experiment is not on learning the names of the kinds of matter formed when baking soda is heated, but on recognizing 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 hypotheses to be tested.

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 each 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 often 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 in which little is known, it is done to find out how nature behaves, or (2) if more is known and 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. In these cases, forcing students to develop a hypothesis that will be confirmed or refuted at the end of the experiment serves no purpose, no matter how 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, The Mass of a Gas, 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 approach.

FOR FORMATIVE ASSESSMENT

6th paragraph

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

Section

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

The Experiment

APPARATUS AND MATERIALS

Pegboard
Small clamp
2 Small test tubes (20 mm × 150 mm)
Stirring rod
Rubber or plastic tubing (45 to 50 cm)
No. 2 one-hole rubber stopper
Rubber band
Right-angle glass bend (5- or 6-mm tubing)
Alcohol burner and fuel (or microburner and supply tubing)
Plastic container
Collection bottle (500 ml)
Test tube rack
Scoopula
Baking soda
Glycerine
Safety glasses
Water
Matches
Tea (250 cm^3 per class)

OVERVIEW AND TEACHING TIPS

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. Always use fire-polished glass tubing and glycerin. Rubber stoppers come with small-diameter holes that 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 to remedy a "floppy clamp" should prevent many problems. Note that pegboard clamps come in two sizes. The small clamp has a longer sleeve, so that it holds objects the same distance from the pegboard as does the larger clamp. If the small clamp does not grasp a small test tube securely, remove the test tube and squeeze 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.

Be sure to use heat-resistant test tubes, such as Pyrex™ or Kimex™. Do not use "culture tubes" as they may shatter when heated. To avoid spillage, the plastic container used to hold the water should be large enough to contain all of the water from the inverted bottle (500 ml) after initially being filled to a depth of three to four centimeters. It would be beneficial if you or your students mark the 3-cm depth on the container before beginning the experiment so that students have a guide line similar to the one shown in Figure 1.1.

If your students are not familiar with a scoopula, introduce it during the pre-lab discussion. If you have plastic test tube racks, you may also want to point out that hot test tubes should not be placed in them.

Students are advised to use an amount of baking soda that stands 0.5 cm high in a test tube. (This is the simplest way to specify the amount. Remember that mass and volume have not yet been introduced.) 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 in the bottle will defeat the purpose of this procedure by drawing the gas that has been collected back into the cooling test tube. In addition, the end of the tube must not be left in the container of water or water will be drawn back into the hot test tube as it cools. Leaving the end of the tube open to the atmosphere will avoid both of these problems.

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 BULLETED QUESTIONS

- The baking soda at the bottom of the test tube looks the same as it did before it was heated.
- 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.
- 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.

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 6 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, as described in the final paragraph of this section, is an excellent demonstration experiment that will help to prepare students for the next experiment.

FOR FORMATIVE ASSESSMENT

3rd paragraph

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

8th paragraph

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

Section

Why is 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 accurate reading of a scale. The purpose of this section is to introduce your students to estimating fractions of a scale division. They will apply this skill to reading rulers and graduated cylinders. The approach taken in the text is to have students realize that not all readings should be rounded to the closest mark on the scale. At this level, however, it is not necessary to push students to always read to the nearest tenth of a division. Realizing that they can increase the accuracy of their measurement by estimating to 0.0, 0.2 or 0.3, 0.5, and 0.7 or 0.8 divisions is sufficient.

For many students, this section will involve a use of the word “scale” that is different from the bathroom scale with which they may be familiar. Confusion over the usage may be increased by the fact that although older, analog bathroom scales have a “scale” that can be read to measure weight, the newer digital models have no such visible scale. They simply provide a visual readout, with no estimation required. It is worth pointing out to students that there is still uncertainty in the readout value. The estimation and rounding have simply been done electronically.

FOR FORMATIVE ASSESSMENT

Section

Report the position of each of the arrows in the figure. (*Note: The illustrations for this question appear on the CD included with this Guide. You may use this master for projection, with a smart board system, or to make a transparency.*)

The four rulers read:
7.37 or 7.38 units;
5.15 units;
3.52 or 3.53 units;
6.00 units.

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

APPARATUS AND MATERIALS

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

OVERVIEW AND TEACHING TIPS

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 adding water, stirring, and pouring off the mixture.

NOTE: Pouring this mixture into a sink can cause expensive plumbing problems, so be sure to provide a disposal container. An alternative that makes it easier to clean the graduated cylinder 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.

SAMPLE DATA AND ANSWERS TO BULLETED QUESTIONS

The results given below are typical:

Volume of dry sand	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%

1.5 Shortcomings of Volume as a Measure of Matter

For the demonstration shown in Figure 1.13, you will need rock salt, a large test tube, a No. 4 one-hole rubber stopper, and a long, straight, glass tube 6 mm in 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 avoid bubbles in the salt solution, use recently boiled water that has cooled to room temperature.

1.6 Mass: The Equal-Arm Balance

Even if your students do not 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, such as the one in Figure 1.15, in front of the class will be helpful. (The balance shown is an *IPS* balance, developed for an earlier edition of *IPS*.)

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 force pulling an object toward the moon. Since that force is only one-sixth of the force pulling the same object toward Earth, 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 consequence of this proportionality is that 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. An 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 the first part of this course is to use only the term "mass," both as a noun and as a verb. The distinction will be made clearer when forces are introduced in Chapter 14.

NOTES

FOR FORMATIVE ASSESSMENT

1st paragraph

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

6th paragraph

Will five grams of wood balance five grams of feathers?

1.7 Single-Pan and Electronic Balances

Most school laboratories now use electronic balances because their use reduces the time required to measure mass. Even so, single-pan balances have been used to teach *IPS* successively for many years.

The basic principle of a single-pan balance is that a single rider of constant mass and permanently attached to be balance beam may be placed at various distances from the fulcrum. This more rapidly accomplishes the same result as placing one of several standard masses at the same distance from the fulcrum of an equal-arm balance. Hence, the use of single-pan balances compared to equal-arm balances requires less time to make a mass measurement. Also no standard masses are dropped on the floor and lost because the standard masses are attached permanently to the beam.

Be sure to teach students that single-pan balances may have one or several beams. Each beam has its own standard mass (or rider). As divisions on the beam's scale represent smaller mass increments, the standard masses (riders) on that beam have less mass.

Electronic balances are now used in many school laboratories. Read the manufacturer's 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 calibration 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.

FOR FORMATIVE ASSESSMENT

1st paragraph

What would be the effect of adding a third beam with a still lighter rider to the double-beam balance shown in Figure 1.17?

1st paragraph

Why does the balance shown in Figure 1.17 not have a third beam and still lighter rider?

EXPERIMENT E

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 to select 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. They also find how reproducible their measurements are and what the sensitivity of their balance is. The experiment is designed to demonstrate the limits of the balance by alternately making repeated measurements of the mass of light and heavy objects. In addition, students find how much mass they need to add to have the balance respond the sensitivity of the balance.

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

The Experiment

APPARATUS AND MATERIALS

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

OVERVIEW AND TEACHING TIPS

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 when obtaining each reading 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 class of masses that should be used with the *IPS* balances. (The mass sets should include only masses from 100 mg to 50 g.) The tolerances given in the table express the range over which the actual masses of the manufactured standards may vary.

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 balance reading	Single-pan balandce reading	*IPS* balance reading
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 balance reading	Single-pan balandce reading	*IPS* balance reading
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, giving a reading different from the previous reading, and "N" indicates no response.

Number of groups of squares added to the balanced penny on different types of balances

	Total Number of Groups of Squares									
Type of 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 BULLETED 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, 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 depend on the graph paper and the type of balance used. For the graph paper with 0.0048 g per group of 10 squares, 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 0.01 g.

  Responding on the average to every third group, the single-pan balance shows a sensitivity of 3×0.0048 g, or about 0.015 g.

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

Type of Balance	Reproducibility (g)	Sensitivity (g)
Electronic	0.01	0.01
Single-pan	0.01	0.015
IPS equal-arm	0.005	0.005

Answers To Problems

The table below classifies problems according to their estimated level of difficulty and the sections to which they relate. 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	8	
3		9, 10, 11,12	13
4-5	14, 15	16, 17	
6-7	18, 19, 20	21, 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. thermometer

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

   50.0 cubic centimeters