DOCUMENT RESUME

ED 477 257 SE 067 618

AUTHOR	Atkinson, Gordon; Heikkinen, Henry; Hearle, Robert
TITLE	Reactions and Reason: An Introductory Chemistry Module. Teacher's Guide.
ISBN	ISBN-06-561220-5
PUB DATE	1978-00-00
NOTE	105p.; Produced by the Chemistry Association of Maryland. For other modules in series, see SE 067 619-630.
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	EDRS Price MF01/PC05 Plus Postage.
DESCRIPTORS	Chemistry; *Instructional Materials; *Interdisciplinary Approach; *Physical Sciences; *Science Curriculum; Science Instruction; Secondary Education

ABSTRACT

This teacher's guide is one in a series of Interdisciplinary Approaches to Chemistry (IAC). The purpose of this guide is to provide information and resources for helping to familiarize students with chemistry and its everyday applications around the world using inquiry and investigations. Contents include: (1) "Chemistry: A Human Activity"; (2) "Measuring Matter"; (3) "Investigating Physical Properties"; (4) "Matter in Motion"; (5) "Chemical Changes"; (6) "The Structure of Atoms"; (7) "The Language of Chemistry"; (8) "The Mole Concept"; (9) "Chemical Bonding"; and (10) "Shapes of Molecules". (YDS)

interdisciplinary
approaches
to chemistry

IAC

TEACHER'S GUIDE

REACTIONS AND REASON

AN INTRODUCTORY CHEMISTRY MODULE

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interdisciplinary approaches to chemistry

IAC

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Henry Heikkinen, 1973–76

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FORM AND FUNCTION: An Organic Chemistry Module	Bruce Jarvis, Paul Mazzocchi
MOLECULES IN LIVING SYSTEMS: A Biochemistry Module	David Martin, Joseph Sampugna
THE HEART OF MATTER: A Nuclear Chemistry Module	Vic Viola
THE DELICATE BALANCE: An Energy and the Environment Chemistry Module	Glen Gordon, William Keifer
COMMUNITIES OF MOLECULES: A Physical Chemistry Module	Howard DeVoe
Teacher's Guides (available for each module)	Teacher's Guide Coordinators: Robert Hearle, Amado Sandoval

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Henry Heikkinen
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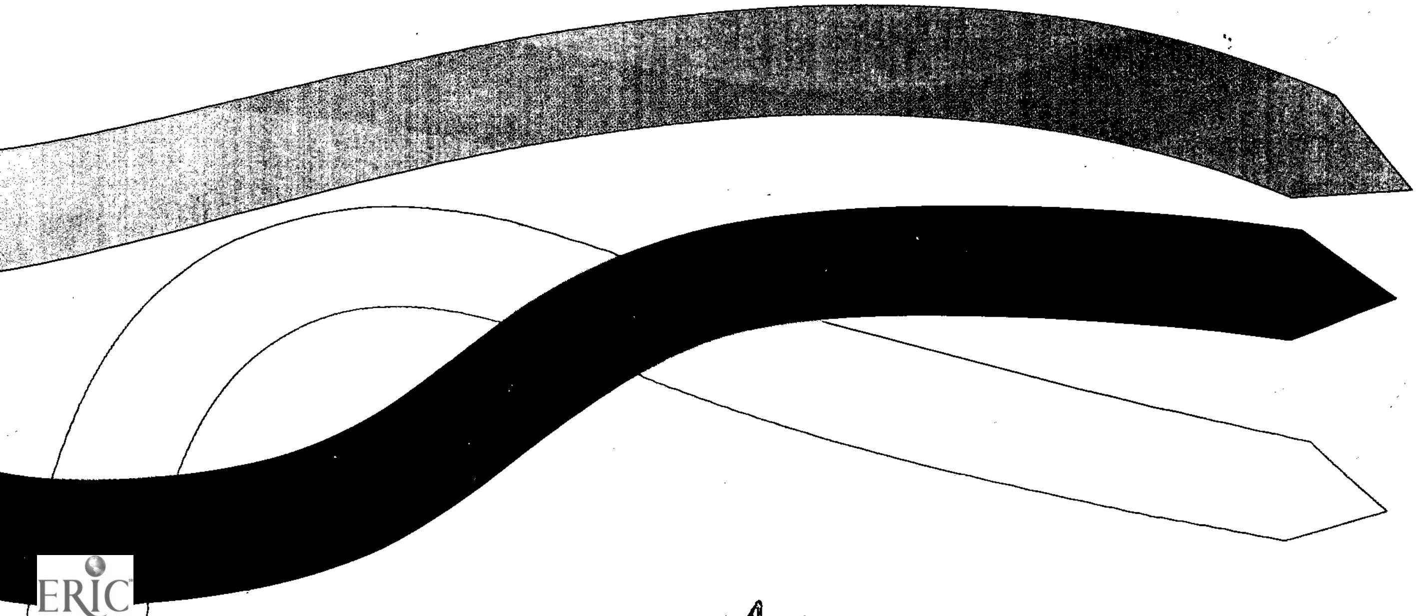
1817
Harper & Row, Publishers
New York   Hagerstown   San Francisco   London



AUTHORS

TEACHER'S GUIDE

REACTIONS AND REASON:
AN INTRODUCTORY CHEMISTRY MODULE

GORDON ATKINSON

Before joining the faculty of the University of Oklahoma in 1972, Gordon Atkinson was a teaching professor at the University of Maryland. Winner of a Fulbright Research Award in Denmark and an Excellence in Teaching Award, and founder of the General Honors Program, Gordon has always been ready to talk with students and teachers everywhere. He is now Chairman of the Chemistry Department at the University of Oklahoma, Dean of the Graduate College, and Vice Provost for Research Administration. He still finds time to teach first year chemistry, conduct high school workshops, and run an active research program in physical chemistry.

HENRY HEIKKINEN

Henry Heikkinen came to the University of Maryland in 1969 from Richfield High School in Minnesota, where he had taught chemistry for seven years. Henry is currently on the faculty at the University of Maryland in both the Chemistry Department and in the Secondary Education Department's Science Teaching Center. Recently he has participated on the American Chemical Society's Writing and Editorial Committees, which drafted *Guidelines for the Preparation and Continuing Education of Secondary School Chemistry Teachers*. Henry served on the Advisory Boards for both *The Science Teacher* and *Chemistry* and directed several NSF-funded implementation projects for teachers. He was Director of the IAC Project from 1973–76 and has played a major role in the design and implementation of the entire IAC program.

ROBERT HEARLE

Robert Hearle came to the University of Maryland in 1970 after working as a research chemist. While at Maryland he taught in the Chemistry and Education Departments, assisted in supervising student teachers in science, and was part of the IAC development team. Bob is now teaching in the Prince George's County, Maryland, school system. His special fields of interest include analytical and organic chemistry and computer-assisted instruction, including the development of a computer-managed independent study program.

STANDARD BOOK NUMBER
06-561220-5

89012MU0987654321

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APPENDIX

Preface

Welcome to IAC Chemistry. Enjoy the year as you and your students explore this important area of science. The *Interdisciplinary Approaches to Chemistry* (IAC) program originated in 1970 when teachers met for the first Regional Educators Annual Chemistry Teaching Symposium held at the University of Maryland. It was at this symposium that chemistry teachers emphasized the need for a new approach to teaching high-school chemistry. With the help of many teacher participants and science education specialists, the first edition of the IAC program was published in 1973. The program's aim was to develop a distinctive, attractive, stimulating chemistry course that provided fresh, new options in chemistry for high-school teachers and their students.

This program gives you, the teacher, the opportunity to make chemistry

activity oriented
enjoyable
flexible
innovative
interdisciplinary
interesting
investigative
provocative
relevant
student-centered

Students throughout this country and in a number of other countries as well have let us know that they like and learn from the IAC modules. As classroom teachers, you have suggested changes to make the modules even better. Our goals are to make chemistry more appealing for an even larger audience of students and to bring to students a very solid experience in up-to-date chemistry.

This teacher's guide was designed so that you can make choices and determine limits for your own class as well as for individual students. Many of the suggestions incorporated in this guide are the results of feedback from other IAC chemistry teachers.

We hope you will find pleasure and satisfaction in using this program to teach chemistry.

Marjorie Gardner
Director
Interdisciplinary Approaches to Chemistry

Introducing the IAC Program

Characteristics of the IAC Program

In developing the IAC program, our goal has been to produce instructional materials that not only present the important concepts and processes of chemistry but also convey the study of chemistry in an interesting, enjoyable, and relevant manner. We believe that the study of chemistry should be extended to a much larger audience of students as part of their general education.

The promotion of scientific literacy is an important goal of IAC. Efforts toward solutions of the great social problems of the world—energy use and abuse, good food and nutrition, population control, environmental protection—require an understanding and appreciation of basic chemistry on the part of all of us.

The IAC modules are independent of one another and can be taught in any order after the students have completed *Reactions and Reason* (or an equivalent introduction to the basic concepts and skills of chemistry). Teachers can also use individual modules to enrich an existing chemistry curriculum. Selected modules serve as minicourses in schools in which a semester or quarter course is a student option. IAC modules are often used in other science courses. (Organic chemistry and biochemistry are used to supplement biology courses, nuclear chemistry and physical chemistry are used as supplements in physics courses, and environmental chemistry is used in earth science courses). Each module can be used to complement integrated science courses.

The modules can be taught in either group or self-pacing modes. (Several definitive articles on self-pacing are listed in *Selected Readings for Teachers.*) IAC chemistry was designed to best serve students at a brisk, purposeful pace guided by clearly stated objectives. There is no need to strive for complete understanding or to drill for competency on ideas in a particular module. The concepts and skills presented in one module will be reinforced in others, permitting the student to move toward mastery by encountering important ideas on several occasions and in different contexts.

An informal writing style, taking into account student reading ability, is part of the text style and design of IAC modules. Student activities and investigations are integrated into the student module text to provide immediate reinforcement of a concept that is being developed. Because of this integration there is no separate laboratory manual. The illustrations, photographs, and cartoons help to keep the module closely tied to the students' needs.

Each module is designed to help the student develop a better conceptual understanding of the material. We have found that the topics and concepts can be easily covered by the average student. For advanced students we have included a wealth of material in both the student modules and the teacher's guides. Many suggestions are provided for interested students to pursue topics presented in the student modules, a feature of the program that helps keep the pace of the material just right for all students in your chemistry course.

Student activities requiring minimal preparation and only a portion of a class period are usually designated as miniexperiments. Other experiments are planned for an entire class period or to extend over several days or weeks of time to get results that will promote interest and understanding. Effort has been made to keep preparation and costs as reasonable as possible.

Interdisciplinary themes have been developed wherever possible. In the biochemistry, energy and environmental chemistry, and nuclear chemistry modules, it has been possible to incorporate some of the important ideas from physics, biology, and the earth sciences into the teaching of chemistry. In other instances, sections of modules such as the bioinorganic section of *Diversity and Periodicity* bring two or more sciences together in a natural learning sequence.

A wide range of experiences in the laboratory contribute to building a strong base for students in developing skills and learning the processes of science. The *concept* and *process* charts in the next section illustrate how important ideas and experiences are introduced and reinforced through the modules.

IAC Concepts

The following chart calls attention to the concepts developed in the IAC chemistry program. Each concept is noted only when it is a major theme of a module. The chart will indicate at which point major concepts appear so that you may construct a program that presents and reinforces the concepts that are important for your students.

Concepts	MODULE: Introductory	Inorganic	Organic	Biochemistry	Nuclear	Environmental	Physical
Physical and Chemical Properties	●	●	●	●	●	●	●
Formula and Equation Writing	●	●	●	●	●	●	●
Elements and Compounds	●	●	●	●	●	●	●
Nomenclature	●	●	●	●	●	●	●
Stoichiometry	●	●				●	●
Mole Concept	●	●		●		●	●
Energy Relationships	●	●	●	●	●	●	●
Atomic Structure	●	●			●	●	
Chemical Bonding	●	●	●	●			●
Shapes of Molecules	●	●	●				
Solids, Liquids, Gases	●	●	●			●	●
Reaction Rates/Kinetics				●	●		●
Acids, Bases, and pH	●	●	●	●		●	●
Oxidation–Reduction	●	●	●	●		●	●
Ionization	●	●		●	●	●	●
Equilibrium		●			●	●	●
Solutions and Solubility	●	●	●	●		●	●
Periodicity	●	●			●		
Gas Laws and KMT	●						●
Scale and Order of Magnitude	●				●	●	●
Metric Measurement (SI)	●	●	●	●	●	●	●

IAC Module Content

REACTIONS AND REASON

An Introductory Chemistry Module

Concepts

- Mixtures and pure substances
- Chemical and physical properties
- Formulas, equations, nomenclature
- Elements and compounds
- Mole concept and stoichiometry
- Solutions
- States of matter
- Energy and kinetic molecular theory
- Reactions
  - Acid—base
  - Oxidation—reduction
  - Precipitation
- Atomic structure
- Bonding
- Molecular shapes

Process Skills

- Observe
- Measure
- Record
- Graph
- Identify
- Calculate
- Interpret
- Classify
- Prepare
- Sublime
- Decant
- Filter
- Separate
- Use symbols
- Use SI Units

DIVERSITY AND PERIODICITY

An Inorganic Chemistry Module

Concepts

- Periodicity
- Metals and nonmetals
- Transition elements
- Crystal packing
- Bonding
- Molecular architecture/structure
- Acids and bases
- Oxidation-reduction
- Coordination compounds
- Trace metals
- Bioinorganic systems

*Process Skills**

- Titrate
- Build models
- Predict
- Extract
- Synthesize
- Purify

FORM AND FUNCTION

An Organic Chemistry Module

Concepts

- Physical and chemical properties
- Bonding
- Families of molecules
- Drugs
- Petroleum products
- Explosives
- Polymers
- Sex attractants
- Chemiluminescence
- Chemical warfare
- Pesticides
- Soaps, detergents
- Isomerization
- Energy relationships
- Acids and bases
- Nomenclature

*Process Skills**

- Build models
- Polymerize
- Synthesize
- Separate and identify
- Chromatography
- Determine melting point
- Purify

*In addition to those process skills introduced in *Reactions and Reason*

IAC Process Skills

Students in the IAC program learn chemistry by actually *doing* chemistry. The process chart highlights the variety of laboratory experiences that a student encounters in each module and the skills that your students can be expected to acquire after completing the laboratory experiences.

Skills	MODULE: Introductory	Inorganic	Organic	Biochemistry	Nuclear	Environmental	Physical
Measure Mass (SI)	●	●	●	●		●	●
Measure Volume (SI)	●	●	●	●		●	●
Measure Temperature/Pressure	●	●	●	●		●	●
Measure pH	●	●		●		●	●
Measure Melting/Boiling Point	●		●				●
Decant/Filter	●	●	●	●		●	●
Characterize/Compare/Identify	●	●	●	●	●		●
Graph	●	●		●	●	●	●
Interpret	●	●	●	●	●	●	●
Synthesize	●	●	●			●	●
Calculate	●	●	●	●	●	●	●
Precipitate	●	●	●			●	●
Titrate		●		●		●	●
Pipet				●			
Analyze Samples	●	●	●	●	●	●	●
Analyze Data	●	●	●	●	●	●	●
Dissolve	●	●	●	●			
Mix or Prepare	●	●	●	●			●
Purify		●	●		●		
Extract		●	●	●			
Build Models	●	●	●				
Observe	●	●	●	●	●	●	●
Record	●	●	●	●	●	●	●
Sublime	●						
Separate (Chromatography)			●				
Separate (Dialysis)				●			●
Elute					●		
Grow Cultures						●	
Use Scientific Notation	●						●
Write and Balance Equations	●	●	●		●		●
Use Metric Measurements	●	●	●	●	●	●	●

7A

MOLECULES IN LIVING SYSTEMS

A Biochemistry Module

Concepts

- Living systems
- Biomolecules
- Amino acids
- Protein structures
- Carbohydrates
- Nucleotides
- Lipids
- Vitamins and hormones
- Biologic function
- Enzyme catalysis
- Metabolism
- Reproduction and growth
- Bonding and structure
- DNA and RNA
- Acids and bases
- Energy pathways

*Process Skills**

- Separate
  - Dialysis
  - Density gradient
- Measure pH
- Prepare enzymes
- Analyze
- Ferment
- Titrate
- Pipet

THE HEART OF MATTER

A Nuclear Chemistry Module

Concepts

- Fundamental particles and forces
- Nuclear properties
- Conservation laws
- Origin of elements
- Radioactive decay
- Half-lives and dating
- Isotopes
- Superheavy elements
- Fusion and fission
- Application of radiation
- Nuclear power
- Nucleosynthesis
- Stellar evolution

*Process Skills**

- Measure radioactive decay
- Measure radiation energies
- Use tracers
- Use logarithms
- Elute
- Use scientific notation
- Write nuclear equations
- Use autoradiography
- Measure radiation in environment

THE DELICATE BALANCE

An Energy and the Environment Chemistry Module

Concepts

- Energy needs
- Energy pollution cycles
- Air pollution
- Stratosphere ozone
- Water pollution
- Food chains
- Toxic substances
- Nuclear radiation
- Recycling
- Environmental economics

*Process Skills**

- Titrate
- Collect samples
- Analyze "real" samples
- Use colorimetry
- Measure pH
- Dilute

COMMUNITIES OF MOLECULES

A Physical Chemistry Module

Concepts

- Scale and order of magnitude
- Gas relationships
- Intermolecular forces
- Liquids and solids
- Solutions
- Colloids
- Energy changes
- Reaction rates
- Chemical equilibrium
- Electrochemistry

*Process Skills**

- Calculate
- Use scientific notation
- Graph
- Separate
  - Dialysis
  - Filtration
- Measure pressure
- Emulsify
- Make serial dilutions
- Make electrochemical cells
- Electrolyze
- Measure pH

*In addition to those process skills introduced in *Reactions and Reason*

Special Features of the IAC Student Modules

Metric System Le Système Internationale (SI) is used throughout the IAC program. This system of measurement has been applied everywhere in the world, and the United States has begun the transition to SI units. You will find extensive discussion of the metric system in *Reactions and Reason: An Introductory Chemistry Module* in both the student text *A-8* and Appendix II. For easy student reference, there is a metric units chart in the appendix of most of the student modules.

Time Machine A feature we call the *Time Machine* appears in the IAC modules in order to present chemistry in a broader context. We have chosen some important events in the history of chemistry that relate to discussions in the student text. These events have been presented in a format that includes important developments in the other sciences and in technology, sports, politics, and the arts that occurred about the same time. The information in the *Time Machines* helps the student grasp particular aspects of chemistry by establishing the social-cultural-political framework in which significant progress was made in chemistry.

Cartoons A popular feature of the IAC program, the chemistry cartoons, gives students a chance to remember specific points of chemistry in another important way—through humor. Many of the cartoons are based on suggestions from students and teachers who use the IAC program.

Safety Laboratory safety is a special concern in any chemistry course. In addition to including safety discussion and guidelines in the appendix of each student module and teacher's guide, experiments have been developed that avoid the use of potentially dangerous chemicals and procedures. Moreover, each experiment that might possibly present a hazard—through fumes, corrosive chemicals, use of a flame, or other conditions—has been marked with a safety symbol to alert students and teachers to employ extra precaution. (See Appendix I of each student module and teacher's guide.) Caution statements, in bold type, also appear in experiments to instruct the student on the specific care required.

Selected Readings Articles and books that tie in with the topics discussed in the IAC program have been listed in the appendix of each student module as well as in the teacher's guide. Encourage your students to use this section. You may wish to suggest other material that you yourself have found interesting and enjoyable.

Illustrations and Photographs The IAC program is highly illustrated to provide relevant and stimulating material that enables the student to relate chemistry to everyday life and that provokes lively discussion. In using some of these illustrations it is not the intention of IAC to endorse any particular product or brand. If a product name appears in a photograph, its intention is only to relate chemistry to life outside the classroom. As you proceed through each section, encourage students to collect photos and illustrations as a basis for further discussion. A display of relevant material that is kept up to date can be an important learning device for many students.

Questions, Problems, and Exercises In addition to the questions that are naturally built into the narratives and the laboratory experiments, a number of questions and problems have been interspersed throughout the modules. You will also find questions and problems in specific, marked sections in the student modules that can be used in a variety of ways as you see fit. These are not planned as tests, because IAC is designed so that mastery of the content and skills can be achieved through the repeated reinforcement of ideas and procedures encountered as a student progresses through the various modules.

Managing the Laboratory

Laboratory preparation is traditionally a demanding, but necessary, and satisfying aspect of chemistry teaching. This remains true in the IAC program because of the strong laboratory orientation of the IAC modules. In IAC, students spend at least 50 percent of their time *doing* chemistry. We have suggested certain techniques and hints that should make preparation for the laboratory less demanding.

In the teacher's guide, hints and suggestions are given for managing each experiment in the laboratory. Share as many of these hints as possible with your students to allow them to participate fully in successful laboratory management. Make sure that you rotate assignments so that all students get a chance to participate in this type of experience.

Preparations and Supplies Student aides can be helpful in preparing solutions, labeling and filling bottles, cleaning glassware, and testing experiments. Consider assigning reliable senior students who have previously taken high school chemistry to be aides in your preparation room each day.

Each experiment has been classroom tested, but you should try each experiment to determine any revisions necessary to meet the special needs of your situation or your students.

Cleaning Up Involve your students in putting away equipment, washing glassware, and storing materials for future use in the laboratory. Taking care of equipment is part of the students' responsibility that we seek to foster.

After completing an experiment, consider packing any specialized equipment or materials in a labeled box or tote tray, which can be stored and ready when the activity is conducted again.

Laboratory Reports and Data Processing Recording data and preparing reports on laboratory experimentation are important skills in all science courses and, of course, are part of the IAC program. Although you may have your own methods of student reporting, some of the suggestions that IAC teachers have found successful have been included for your consideration.

It is helpful for students to keep a laboratory notebook. A quadrille-ruled laboratory notebook with a sheet of carbon paper allows a student to produce two data sheets and copies of the report summary. Each page can be permanently retained in the notebook and the duplicate copy can be submitted for evaluation or tabulation.

You will find it helpful if data summaries, including all written observations, are submitted at the end of the laboratory period, even though the calculations and/or questions are not due until a later date.

You will then be able to assemble a summary of all student results for a particular investigation on the chalkboard or on an overhead transparency. Such data permit useful discussion on determining a "best" value through a median or mean value, a histogram, or through some other visual report of overall student results.

A realistic view of laboratory work suggests that in the most fundamental sense there are no wrong laboratory results. All students obtain results consistent with the particular experimental conditions (either correct or incorrect) they have established. Because careful work will yield more precise results, encourage each student to take personal pride in experimental work. If students disagree on a result, discuss the factors that might account for the difference. A student who provides a thoughtful analysis of why a particular result turned out to be "different" (incomplete drying, a portion of the sample was spilled, etc.) deserves credit for such interpretation.

Laboratory Safety The IAC program introduces many new laboratory procedures and activities to students. To use the IAC program safely you should become thoroughly familiar with all student activities in the laboratory. Do all the experiments and carry out all the demonstrations yourself before presenting them to your class. We have tested each experiment and have suggested the use of chemicals that provide the least chance of causing a safety problem in the laboratory. The teacher's guide has many suggestions to help you provide your students with safe laboratory experiences. Have the students read *Appendix I: Safety*, and conduct a brief orientation to laboratory safety before the students encounter their first laboratory experience in each module. Review when necessary and discuss precautions and safety each time a safety symbol appears in the student text. In addition, the *Suggested Readings* in this teacher's guide cites safety manuals that give detailed instructions on the handling of hazardous chemicals, disposal of chemicals, and general laboratory safety.

Materials for IAC In consideration of the increasing costs for equipment and supplies as well as decreasing school budgets, we have tried to produce a materials list that reflects only the quantities needed to do the experiments, with minimal surplus. Thus, the laboratory preparation sections contain instructions for only a 10 to 20 percent surplus of reagents (rounded off to the nearest convenient quantity). Add enough materials for student repeats and preparation errors.

Nonexpendable Materials for IAC

Quantities listed are for a class of 30 students working in pairs.

*Optional Items. These items depend on teacher choice. We have listed substitutions in the experiment discussion. Consult the specific experiment in the teacher's guide to determine use and quantities.

TG—Refer specifically to teacher's guide for source or information.

G—Local purchase or collected from home.

	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Alligator clips						30		30	
Aluminum foil	1*							1 sm. roll*	G
Aluminum nuts and bolts	250*							250 g*	
Aluminum sheet, 5 × 5 × 0.08-cm					60–75			60–75 sheets	
Aluminum wire				150*				150 cm*	
Aspirators				15		15		15	
Bags, clear plastic (sandwich size)	15							15	G
Balances, 0.01 g sensitivity								8–15	
Balls, Styrofoam, 20-mm diameter	60	300						300	
Balls, Styrofoam, 25-mm diameter (approx. 100–200/set)	30	120		2500–3000				2500–3000	
Balls, Styrofoam, 50-mm diameter	30			84*				84*	
Battery jars, rectangular							1	1	
Beakers, 50-cm³	60*	15	30	30		45	45	45	
Beakers, 150-cm³	15		30	15		30	30	30	
Beakers, 250-cm³	15	30	30	15			15	30	
Beakers, 400-cm³	30	15				15	15	30	
Beakers, 600-cm³	15			15		15*	15	15	
Bicycle pumps (or other inflating devices)							15	15	TG, G

Blender			1					1	
Bottles, with tight caps, 200-cm³ or larger							15	15	G
Bottles, with tight caps, 500-cm³ or larger							15	15	G
Boxes, plastic, and false bottoms				15				15	TG
Brass fittings	250*							250 g*	G
Büchner funnels, 91-mm diameter, and adapters				15				15	
Bunsen burners	15	15	15	15		15	15	15	
Burets, 50-cm³		5–10	15	30			18	30	
Burets, Teflon stopcock			1–3*					1–3*	
Buret clamps, double		5–10	15	15			15	15	
Capillary tubing, 0.75-mm–1.25-mm bore						5		5 m	
Centrifuge			1*				1*	1*	
Clamps, universal	30	15	15	15	30	15		30	
Clock, for timing		1	1			1		1	
Conductivity apparatus (dry cell, bulb, and leads)				15 sets				15 sets	
Copper sheet, 5 × 5 × 0.08-cm					60–75			60–75 sheets	
Copper shot	250*			150*				250 g*	
Copper strips, 2 × 10 × 0.08-cm						15		15 strips	
Copper wire				150*				150 cm*	
Corks, assortment		1		1				1	
Corks, for test tubes		75						75	

Nonexpendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

*Optional Items. These items depend on teacher choice. We have listed substitutions in the experiment discussion. Consult the specific experiment in the teacher's guide to determine use and quantities.

TG—Refer specifically to teacher's guide for source or information.

G—Local purchase or collected from home.

	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Dropper bottles, 50-cm³	60*	5	30	30*		16		30	
Dry cells, #6, 1.5 volts						30	5–15	30	
Drying oven				1*				1*	
Electrodes (e.g., platinum)							10–30	10–30	
Erlenmeyer flasks, 50-cm³							15	15	
Erlenmeyer flasks, 125-cm³		15		15		15*	60	60	
Erlenmeyer flasks, 250-cm³		15	15	45		15	15	45	
Erlenmeyer flasks, 500-cm³		15						15	
Evaporating dishes, #0	15							15	
File, triangular						1		1	
Film holder, Polaroid type 545					1–5			1–5	
Filter flasks, 500-cm³ or smaller				15		15		15	
Flashlight bulbs, PR-2 *or* PR-4						15		15	G
Funnels, 75-mm diameter, and supports	15	15	15	15		15–45	30	30	
Glass beads *or* marbles	250*							250 g*	
Glass plates, 8 × 8-cm, clear (or clear plastic)				30*				30*	
Graduated cylinders, 10-cm³	15	15	30	15		15	15	30	
Graduated cylinders, 50-cm³	15	15		15		15	15	15	

Graduated cylinders, 100-cm^3	15					15	15	15	
Graphite		*		5		*		5 g	G
Grater, cabbage			2–5					2–5	G
Hot plates				1–10*				1–10*	G
Iron nails	250*							250 g*	G
Iron wire				150*				150 cm*	
Jars, 120-cm^3, widemouth with lids		15	15					15	G
Lead sheet, 5 × 5 × 0.08-cm					60–75			60–75 sheets	
Lead shot	250*							250 g*	
Lead strips, 2 × 10 × 0.08-cm						30		30 strips	
Lead wire				150*				150 cm*	
Magnets, bar	15							15	
Magnets, disc, 1-cm				100				100	
Magnets, ring				10				10	
Magnifying glasses	15						15	15	
Medicine droppers	60	15	15	30		30		60	
Meter sticks						15		15	
Minigenerators, ^{113}Sn/^{113m}In and ^{137}Cs/^{137m}Ba					1–15 ea			2–30	TG
Mirrors		1–5						1–5	G
Model kits, DNA			1–15*					1–15*	TG
Model kits, molecular		15*	15*	15*				15*	TG

Nonexpendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

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G—Local purchase or collected from home.

	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Molybdenum wire				150*				150 cm*	
Mortar and pestle			15	15*				15	
Overhead projector and screen				1*				1*	
Pans (gas collection over water)							15	15	
Peas, dried	400							400 g	G
Petri dishes, top and bottom, 8–15-cm diameter, Pyrex				15			15	15	
pH meter							1*	1*	
Plastic bead hydrometers			15					15	TG
Platinum wire				30*				30 cm*	
Potassium chloride, reagent					100			100 g	
Radiation detectors *or* counters (e.g., Civil Defense)					1–15			1–15	G
Rice, non-instant	200							200 g	G
Ring stands and rings	15	17	15	15	15	15	15	17	
Rubber stoppers, assortment	1	1	1	1	1	1	1	1	
Rubber stoppers, #2, 1–hole	15							15	
Rubber stoppers, #2, 2–hole	15							15	
Rubber stoppers, #2, solid	250*							250 g*	
Rubber stoppers, #4, solid							15	15	

14 A

Rubber stoppers, #4, 2–hole							15	15	
Rubber stoppers, #5, 2–hole		15						15	
Rubber stoppers, #6, 2–hole (to fit 250-cm³ Erlenmeyer flasks, regular size mouth)				15				15	
Rubber tubing, 9-mm (3/8") I.D., heavy wall (15 lengths)	15			15		15	15	900 cm	
Rulers, metric, 15-cm, heavy plastic					15	15		15	
Scissors				15				15	G
Separatory funnels, 250-cm³				3				3	
Slide projector							1	1	
Spatulas	15	15	15	15		15	15	15	
Spectrophotometer							1–3	1–3	
Spectrophotometric tubes (cuvettes)							15	15	
Spot plates (or see watch glasses)						30		30	
Stirring rods	15	15	30			30	30	30	
Syringe, hypodermic, and needle, 5-cm³						1		1	
Test tubes, 13 × 100-mm	150	75						150	
Test tubes, 18 × 150-mm	60	30	120	240		210	60	240	
Test tubes, 25 × 200-mm			60				15	60	
Test-tube clamps	15	15	15	15				15	
Test-tube racks	15	15	15	15		15	15	15	
Thermometers, −10°C to 110°C	15	15	15	15		15	15	15	
Thermometers, −10°C to 260°C		15						15	

Nonexpendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

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	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Toothpicks	1	5*						1 box	G
Trays, 60 × 60 × 5-cm (approx.)						15		15	
Triangle, clay	15	15	15					15	
Tungsten wire				150*				150 cm*	
Ultraviolet light source		1*	1*					1*	
Uranium salts					5			5 g	
Vacuum pump and bell jar	1*							1*	
Vials, 30-cm³				15–120				15–120	
Wash bottles		15				15*		15	
Watch glasses, 90-mm diameter	15			30			15	30	
Wire, insulated						45		45 lengths	
Wire gauze, asbestos centers	15	15	15	15		15	15	15	
Wire gauze, plain	15	15						15	
Zinc strips, 2 × 10 × 0.08-cm						30		30 strips	
Zinc wire				150*				150 cm*	

COMPOSITION OF SOME INORGANIC ACIDS AND BASES

	Molar Mass	*Molar Concentration*	*Density g/cm³*	*Mass Percent*	*Cubic Centimeters Per Liter for 6 M Solution*
Acetic acid	60.05	17.5	1.05	99–100% CH_3COOH	343
Ammonium hydroxide	35.05	14.8	0.90	28–30% NH_3	400
Hydrochloric acid	36.46	12.0	1.18	36.5–38% HCl	500
Nitric acid	63.01	15.8	1.42	69–71% HNO_3	379
Phosphoric acid	98.00	14.7	1.7	85% H_3PO_4	408
Sulfuric acid	98.08	18.0	1.84	95–98% H_2SO_4	333

SCIENCE SUPPLY SOURCES

In planning your own IAC Chemistry course, you may find it useful to have catalogs of science equipment and supplies on hand, both for ordering and for reference purposes. You may wish to request catalogs from these companies, as well as others.

Carolina Biological Supply Co.
Burlington, NC 27215

Central Scientific Co., Inc.
2600 South Kostner Avenue
Chicago, IL 60623

Fisher Scientific Company
711 Forbes Avenue
Pittsburgh, PA 15219

La Motte Chemical Products Co.
Box 329
Chestertown, MD 21620

Sargent-Welch Scientific Co.
7300 North Linder
Skokie, IL 60077

Science Kit Inc.
777 East Park Drive
Tonawanda, NY 14150

Scientific Products
1430 Waukegan Road
McGaw, IL 60085

Turtox/Cambosco
Macmillan Science Co., Inc.
8200 South Hoyne Avenue
Chicago, IL 60620

Ward's Natural Science Establishment, Inc.
P.O. 1712
Rochester, NY 14603

Wilkens-Anderson Company
4525 West Division Street
Chicago, IL 60651

The following company offers chemicals packaged in a size convenient for use with the IAC program. Write for its list.

Reagents, Inc.
4746 Sweden Road
P.O. Box 15834
Charlotte, NC 28210

Expendable Materials for IAC

Quantities listed are for a class of 30 students working in pairs.

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TG—Refer specifically to teacher's guide for source or information.

G—Local purchase or collected from home.

	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Acetic acid, glacial		275		150		35	350	825 cm^3	
Acetic anhydride		175						175 cm^3	
Acetone	900	80		800				1780 cm^3	
Acetylacetone (2,4-pentanedione)				600				600 cm^3	
Adenosine triphosphate (ATP)			50					50 mg	
Adipyl chloride		15						15 g	
Aluminum foil					1			1 large sheet	G
Aluminum wire, 18 ga. or heavier	25							25 g	G
Aluminum nitrate, $Al(NO_3)_3 \cdot 9H_2O$				6				6 g	
Aluminum sulfate, $Al_2(SO_4)_3 \cdot 18H_2O$				90				90 g	
Ammonia, conc. (see ammonium hydroxide)									
Ammonium acetate, NH_4CH_3COO							125	125 g	
Ammonium aluminum sulfate, $NH_4Al(SO_4)_2 \cdot 12H_2O$				60				60 g	
Ammonium chloride				150			100	250 g	
Ammonium hydroxide, conc.	20			1000			750	1800 cm^3	
Ammonium molybdate, $(NH_4)_2MoO_4$							20	20 g	
Ammonium peroxydisulfate (ammonium persulfate), $(NH_4)_2S_2O_8$e						50		50 g	
Amyl alcohol (see 1–pentanol)									

Ascorbic acid							5	5 g	
Aspirin, commercial		15						15 tablets,	G
trans-Azobenzene		0.2						0.2 g	
Balloons, round				150				150	G
Bar soap (castile)							1	1 g	G
Barium chloride							5	5 g	
Boiling chips	10	5				5		20 g	
Bromine water				25				25 cm³	
Bromocresol green (indicator)	0.05							0.05 g	
Cabbages (fresh)			3					3	G
Calcium acetate						45		45 g	
Calcium carbonate		25					1	30 g	
Calcium hydroxide	1							1 g	
Calcium nitrate, tetrahydrate				11			3	14 g	
Can lids, 10-cm diameter	15	30						45	G
Candles	15							15	G
Capillary tubes (see melting-point tubing)									
Charcoal, powdered				15				15 g	
Chlorine water *or* commercial chlorine bleach				100				100 cm³	G
Chromatography sheets (thin layer), 2.5 × 10-cm (Eastman Chromatogram #6061, silica gel)		30						30 sheets	
Chromium(III) chloride, hexahydrate		10		45				55 g	

Expendable Materials for IAC (Cont'd)

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	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Cobalt(II) carbonate				45				45 g	
Cobalt(II) chloride, hexahydrate				500				500 g	
Cobalt(II) nitrate				170				170 g	
Copper, metal turnings	45							45 g	
Copper(II) oxide	60							60 g	
Copper(II) sulfate, pentahydrate	17	10	25	600		140		800 g	
Cotton cloth (dish toweling)						1200		1200 cm^2	G
Cups, Styrofoam			15			45		60 cups	G
Cyclohexane	250*	200						200 cm^3	
Cyclohexene		50						50 cm^3	
Detergent (several brands)							1–2	1–2 g each	G
Dialysis tubing, 1.6-cm diameter			180			600		800 cm	
para-Dichlorobenzene		25						25 g	
2,6-dichlorophenolindophenol, sodium salt (DPIP)			0.1					0.1 g	
Dithizone				0.1				0.1 g	
Drano, Vanish, Saniflush, etc.				1				1 can each	G
EDTA, reagent (ethylene dinitrilo tetraacetic acid, disodium salt)							45	45 g	
Eggs (fresh)			2					2	G

Epoxy cement						1		1 set tubes	G
Eriochrome black T (indicator, powder)							1	1 g	
Ethanol (ethyl alcohol), denatured	250	1000		2500		1000	150	5 liters	
Ethylenediamine				300				300 cm^3	
Filter paper, 12.5-cm diameter	65	15		100		75	30	300 sheets	
Filter paper, medium weight, 9-cm diameter (for Büchner funnels)				200				200 sheets	
Fireflies			—					—	TG
Food coloring	1*					1		1 set	G
Formaldehyde, 40 percent							0.5	0.5 cm^3	
Fructose			30					30 g	
Galactose			30					30 g	
Gelatin			30					30 g	
Glass tubing, 6–8-mm diameter	5	20		5				30 m	
Glass tubing, 5-mm diameter							5	5 m	
Glucose (dextrose)			50					50 g	
Glycerol							20	20 cm^3	
Graph paper, linear	60		60	30	30	30		210 sheets	
Graph paper, semilog					30			30 sheets	
Hearts, fresh chicken			3–5					3–5	G
Hexamethylene diamine		15						15 g	
n-Hexane (see petroleum ether)									

Expendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

*Optional Items. These items depend on teacher choice. We have listed substitutions in the experiment discussion. Consult the specific experiment in the teacher's guide to determine use and quantities.

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	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Hydrobromic acid, conc.				250				250 cm³	TG
Hydrochloric acid, conc.	650	150	20	850	20	190	50	2000 cm³	
Hydrogen peroxide, 30 percent				1000			0.2	1050 cm³	
Hydrogen peroxide, 3 percent	200	200	100					500 cm³	G
Hydroxylamine hydrochloride, $NH_2OH \cdot HCl$							15	15 g	
Iodine, solid	10		4	5				20 g	
Iodine solution				50				50 cm³	
Iron, metal powder	100						0.5	105 g	
Iron(III) chloride, hexahydrate		2		45				47 g	
Iron(III) nitrate, $Fe(NO_3)_3 \cdot 9H_2O$				10		5		15 g	
Iron(II) sulfate (or iron wire)							1.5	1.5 g	
Lactose			30					30 g	
Lead chloride	30							30 g	
Lead nitrate	8.2			5				13.5 g	
Lithium, metal				5*				5 g*	
Litmus paper, red and blue	15*	1		15				15 vials each	
Liver juice *or* blood			15					15 cm³	G
Luminol		3						3 g	

Lycopodium powder *or* chalk dust						10		10 g	
Magnesium nitrate				12			3	15 g	
Magnesium sulfate, heptahydrate		10	1				5	16 g	
Malonic acid			2.1					2.1 g	
Maltose			30					30 g	
Manganese dioxide	10		5					15 g	
Manganese sulfate, tetrahydrate							120	120 g	
Marble chips, $CaCO_3$	100							100 g	
Masking tape					1	1		1 roll	G
Meat tenderizer			25					25 g	G
Melting-point tubes (capillary)		45						45 tubes	
Mercury, metal						5		5 cm^3	
Mercury(II) chloride							30	30 g	
Methanol (methyl alcohol)	275	400						675 cm^3	
Methyl orange (indicator)						0.1	0.1	0.2 g	
4-methyl-2-pentanone (methyl isobutyl ketone *or* MIBK)				250				250 cm^3	
2-methyl-2-propanol (*t*-butanol)	500							500 cm^3	
Methylene blue (indicator)	0.1*						0.2	0.3 g	
Methylene chloride				250				250 cm^3	
Milk, skim *or* powdered			2000			600		2600 cm^3	G
Mineral oil		2100				750		2850 cm^3	G

Expendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

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	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Monosodium glutamate (MSG)			20					20 g	G
N-(1-napthyl)-ethylene diamine dihydrogen chloride							0.2	0.2 g	
Napthalene		5						5 g	
Ninhydrin			1.5					1.5 g	
Nitric acid, conc.	120					2	110	235 cm^3	
Nitrilotriacetic acid, sodium salt, $N(CH_2COO)_3HNa_2 \cdot H_2O$ *or* $N(CH_2COONa)_3 \cdot H_2O$ (NTA)				8				8 g	
1-octanol (octyl alcohol)		50						50 cm^3	
Oleic acid						1		1 cm^3	
Orange IV *or* thymol blue (indicators)						0.1		0.1 g	
Paper clips *or* 150-cm copper wire		15						15 clips	G
Paraffin		5						5 g	G
Pararosaniline hydrogen chloride							0.2	0.2 g	
1-pentanol (*n*-pentyl alcohol *or* amyl alcohol)		50						50 cm^3	
Petroleum ether *or* *n*-hexane (Skelly B, b.p. 60–80°C)		400	750					1150 cm^3	
pH paper, universal wide range	30		50				200	300 strips	
1,10-phenanthroline							0.2	0.2 g	
Phenolphthalein indicator, solution			1	1			1	1 dropper bottle (50-cm^3)	
Phosphate detergent							20	20 g	

Phosphoric acid							100	100 cm^3	
Pipets, 10-cm^3, with bulbs, disposable			15					15	
Pipets, 1-cm^3, with bulbs, disposable			45				3–15	48–60	
Polaroid film, Type 57 (B&W)					15			15 sheets	
Potassium aluminum sulfate (alum), $KAl(SO_4)_2 \cdot 12H_2O$				100				100 g	
Potassium bromide				100				100 g	
Potassium chloride		10		1				11 g	
Potassium dichromate, $K_2Cr_2O_7$				10*				10 g*	
Potassium iodate							0.2	0.2 g	
Potassium iodide	8.5		10	2		40	25	90 g	
Potassium iron(III) cyanide		10						10 g	
Potassium nitrate				10*				10 g*	
Potassium permanganate		2		15				17 g	
Potassium thiocyanate, KSCN						1		1 g	
2-propanol (2-propyl alcohol)		300						300 cm^3	
Propionic acid			1.5					1.5 g	
Pyridine			20					20 cm^3	
Rennet tablets			15					15 tablets	G
Salicylic acid		150						150 g	
Sand, SiO_2	30		15					45 g	G
Soap (castile)				6			1	7 g	G

Expendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

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G—Local purchase or collected from home.

	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Soda water (club soda)							1500	1500 cm³	G
Sodium, metal				10*				10 g*	
Sodium bicarbonate		10						10 g	
Sodium bisulfite, $NaHSO_3$							0.2	0.2 g	
Sodium carbonate, anhydrous			100	3			2	105 g	
Sodium chloride		850	50	10*	100		50	1100 g	
Sodium citrate			180					180 g	
Sodium hydroxide	120	200	65	120		150	180	900 g	
Sodium iodide							35	35 g	
Sodium nitrate, $NaNO_3$	50			10*				50 g	
Sodium nitrite, $NaNO_2$				450			16	475 g	
Sodium phosphate, dibasic, heptahydrate, $Na_2HPO_4 \cdot 7H_2O$			60					60 g	
Sodium phosphate, monobasic, monohydrate, $NaH_2PO_4 \cdot H_2O$			30					30 g	
Sodium potassium tartrate			12					12 g	
Sodium succinate, hexahydrate			6					6 g	
Sodium sulfate, anhydrous, Na_2SO_4							2	2 g	
Sodium sulfite, Na_2SO_3							0.5	0.5 g	
Sodium tetraborate, $Na_2B_4O_7$				6				6 g	

Sodium thiocyanate, NaSCN				100				100 g	
Sodium thiosulfate, pentahydrate, $NaS_2O_3 \cdot 5H_2O$						750	15	800 g	
Sodium triphosphate, $Na_5P_3O_{10}$				10			10	20 g	
Span 40 (sorbitan monopalmitate)						60		60 g	
Spoons, plastic			30					30 spoons	G
Starch, soluble			3			1	1	5 g	G
Stopcock grease				1				1 tube	
Sucrose (sugar)		25	175					200 g	
Sudan III *or* Sudan IV dye						5		5 g	
Sulfamic acid							3	3 g	
Sulfanilamide							20	20 g	
Sulfur, flowers	110							110 g	
Sulfur, lump				50*				50 g*	
Sulfuric acid, conc.		100				350	375	850 cm^3	
Tape, clear (or glue)				1				1 roll	G
Tartaric acid							2	2 g	
Test tubes, 18 × 150-mm (hard glass)	30							30	
Toluene		225		900*				225 cm^3	
Trichlorotrifluoroethane (TTE)	300			300				600 cm^3	
Tween 40 (polyoxyethylene sorbitan monopalmitate)						60		60 g	
Urea				300				300 g	

Expendable Materials for IAC (Cont'd)

Quantities listed are for a class of 30 students working in pairs.

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	Introductory	Organic	Biochemistry	Inorganic	Nuclear	Physical	Environmental	Total	Order Note
Vegetable oil		150	300					450 cm^3	G
Vinegar				500				500 cm^3	G
Water, distilled						14 000		14 000 cm^3	G
Wood splints	30							30	
Zinc, mossy	10							10 g	
Zinc, 16–20 ga.-sheets	300							300 cm^2	
Zinc sulfate, heptahydrate, $ZnSO_4 \cdot 7H_2O$						300		300 g	

Evaluating Student Performance

There are many ways of evaluating your students' performance. One of the most important methods is observing your students as they proceed through the IAC program. IAC has developed a series of attitude, skill, and knowledge tests for use in the program. These have been incorporated into the student modules and teacher's guides so that they may be used by teachers in any way they choose throughout the course. These test items have been suggested and tested by IAC classroom chemistry teachers. You are encouraged to add these to your own means of student evaluation.

Questions, problems, and exercises have been incorporated into the student module text and illustration captions. In this revision we have added questions to the ends of many sections in the student modules. Sometimes questions are scattered throughout the text in appropriate places. There are also suggestions for evaluation at the end of each module section in the teacher's guide. We have included module tests at the end of each teacher's guide. Answers to all of the evaluation items are included in the teacher's guide to help you in your classroom discussion and evaluation.

An IAC comprehensive examination that can be given at the end of your chemistry course to test for both skill-centered and knowledge-centered areas is available from the publisher as a separate item.

Finally a *Student Opinion Survey* is included to help you evaluate your students' attitudes toward this program.

Student Opinion Survey in Chemistry

Use The statements appearing in the student opinion survey provide a general measure of a student's attitude toward the study of chemistry. The survey should be anonymous—ask students not to identify themselves on the survey sheet. Many teachers give such a survey at least twice during the school year—once at the start of the course, and again several weeks before the end of the school year. These data permit changes in class attitudes to be assessed. This student opinion survey can also be used as a comparative measure of student attitudes in any of the chemistry courses you teach.

Scoring In determining a student's attitude score, it is first necessary to identify the ten favorably worded statements from the ten unfavorably worded statements. Use the two sets of guide arrows on the answer sheet on page I-28 of the teacher's guide. Duplicate and cut out the answer keys. Place each edge of the sheet next to the student survey form. A student's attitude score is found by adding the point values assigned to each of the twenty statements, following the point values shown. Note that in each case the most favorable student response ("SA" item) is assigned 5 points and that the point value decreases until it becomes one point.

Interpretation The highest or most favorable attitude score possible is 100 (20 items × 5 points per item). The most unfavorable attitude score possible is 20 (20 items × 1 point per item). Scores above 60 represent increasing degrees of favorability toward chemistry study (maximum 100). Scores below 60 indicate varying degrees of unfavorability toward studying chemistry (minimum 20).

Favorably-worded items

Point values to be used
in scoring these items:

SA	A	U	D	SD
5	4	3	2	1

← **1.**

← **3.**

← **5.**

← **6.**

← **10.**

← **13.**

← **14.**

← **16.**

← **17.**

← **20.**

Unfavorably-worded items

Point values to be used
in scoring these items:

SA	A	U	D	SD
1	2	3	4	5

2. →

4. →

7. →

8. →

9. →

11. →

12. →

15. →

18. →

19. →

Student Opinion Survey

Each statement in this survey represents an opinion that a student might have about studying chemistry. Indicate your current reaction to each statement by putting an X in the box that most closely corresponds to your own feelings.	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
1. I like to learn about chemistry.					
2. Chemistry frightens me.					
3. Everyone should learn something about chemistry.					
4. I feel hopelessly lost in this chemistry course.					
5. Chemistry is an interesting subject.					
6. I actually enjoy learning chemistry.					
7. As I learn more chemistry, I am less interested in studying it.					
8. I dislike chemistry.					
9. Chemistry is dull.					
10. Chemistry is a subject that I can understand.					
11. I would not encourage anyone to take this chemistry course.					
12. This chemistry course is a pain.					
13. Chemistry class is interesting.					
14. Chemistry is one of my favorite subjects.					
15. Chemistry is too abstract and theoretical for me.					
16. My feeling toward chemistry is favorable.					
17. I would recommend this chemistry course to a friend.					
18. I am not interested in learning chemistry.					
19. Chemistry is one of the worst subjects I have taken.					
20. I feel at ease in chemistry class.					

'f you have any additional comments about any of these areas, use the back of this sheet.

Selected Readings for Chemistry Teachers

GENERAL

Alyea, Hubert, and Dutton, Frederic B. *Tested Demonstrations in Chemistry*. Easton, PA: Chemical Education Publishing Co., 1965. Paperback.
A comprehensive collection of demonstrations in all fields of chemistry, taken from the *Journal of Chemical Education*. A gold mine of ideas.

American Chemical Society. *Guidelines and Recommendations for the Preparation and Continuing Education of Secondary School Teachers of Chemistry*. Washington, D.C.: American Chemical Society, 1977.
Provides specific suggestions for in-service continuing education programs for high school chemistry teachers; accompanied by action recommendations for school officials, agencies, and others involved in supporting secondary school chemistry teaching.

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Similar in format to the *Reader's Guide to Periodical Literature*, this cumulative index covers semitechnical periodicals in chemistry and other fields.

Chemical and Engineering News, American Chemical Society, 1155 16th Street, N.W., Washington, D.C. 20036. Published weekly.
Contains current information on chemical and engineering topics, including articles and notes devoted to aspects of chemical education.

Chemistry, American Chemical Society, 1155 16th Street, N.W., Washington, D.C. 20036. 10/yr.
Contains articles on interdisciplinary topics and their relations to chemistry; intended for high school and introductory college students.

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CHEM 13 NEWS, Department of Chemistry, University of Waterloo, Waterloo, Ontario N2L 3G1. 9/yr.
News and practical suggestions for high school teaching.

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International Newsletter on Chemical Education, IUPAC, Pergamon Press, Headington Hill Hall, Oxford, England. Semi-annual.
News from international chemical circles.

Journal of Chemical Education, Circulation Service, 119 W. 24th Street—4th Floor, New York, NY 10011. Published monthly.
Contains a number of scholarly articles on chemical theory, a discussion of teaching techniques and audiovisual materials useful in the classroom. A new section for high school chemistry has been added.

Journal of College Science Teaching, National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C. 20009. Published quarterly.
Articles on chemistry are included, along with articles on the concepts and methods of science teaching. This journal is also a good source for current books, audiovisual materials, equipment, and supplies.

The Physics Teacher, American Association of Physics Teachers, Graduate Physics Building, State University of New York, Stony Brook, NY 11794. 9/yr.

Science, American Association for the Advancement of Science, 1515 Massachusetts Avenue, N.W., Washington, D.C. 20005. Published weekly.
Contains articles dealing with pertinent scientific issues; also includes a number of descriptive and evaluative book reviews and research reports.

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Each volume contains reviews of science books covering all age levels.

Science News, Subscription Department, 231 West Center Street, Marion, OH 43302. Published weekly.

The Science Teacher, National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C. 20009. Published monthly. Magazine covers a variety of scientific fields; also includes articles about science teaching techniques. A section of the journal is devoted to descriptive book reviews, discussions of new films and equipment.

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A descriptive, annotated bibliography of paperbacks and general chemistry books for the student, teacher, and general reader.

THE NATIONAL SCIENCE TEACHERS ASSOCIATION SELF-ASSESSMENT MATERIALS

Guidelines for Self-Assessment of Secondary-School Science Programs.

I. Our School's Science Curriculum (471-14672, $1.00 each).
II. Our School's Science Teacher (471-14674, $1.00 each).
III. Science Student/Teacher Interactions in Our School (471-14676, $1.00 each).
IV. Facilities and Conditions for Science Teaching in Our School (471-14678, $1.00 each).

Report Form, 2 copies (471-14680, $1.00 each).

Complete self-assessment package, including one copy of each of the four modules, 2 report forms, and a preface (471-14682, $5.00).

Add $0.50 for handling and mailing. Postage will be charged on billed orders.

Order from: National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C. 20009.

Introducing Reactions and Reason

Reactions and Reason: An Introductory Chemistry Module serves as an entree to the *INTERDISCIPLINARY APPROACHES TO CHEMISTRY (IAC),* a program consisting of interchangeable instructional modules. As a door-opener, *Reactions and Reason* should be looked upon as an introduction to chemistry, not as a comprehensive text. You need not strive for complete mastery of the concepts and ideas explored here; many of the topics will be covered in greater depth in subsequent modules. You should plan on spending no more than about nine to ten weeks in teaching this introductory module to an average class of high-school students. *If you dwell too long on this module, you will do yourself and your students a disservice by limiting opportunities to use other modules to reinforce and extend the concepts and skills introduced here.*

Many students enter the chemistry classroom with a mingled sense of awe, curiosity, excitement, and—a fear of chemistry. Recognizing this, we have structured initial concept development at a slow and somewhat deliberate pace. By some standards, the initial student activities in this module may seem obvious and trivial, but extensive classroom experience has shown that these activities provide students with a reassuring feeling of success and accomplishment. This approach seems to dispel anxiety about the course, and, at the same time, it provides a strong motivational setting for the rest of the module.

Reactions and Reason: An Introductory Chemistry Module establishes the foundation for the subsequent study of the other modules in IAC.

The goal of this *Teacher's Guide* is to convey the spirit and strategies of the module to you as the teacher. Much of the information contained in this guide has been based on feedback we have received from teachers since IAC became available for classroom use. We acknowledge all such assistance with gratitude and continue to welcome your suggestions and criticism.

Module Concepts

CHEMISTRY: A HUMAN ACTIVITY

- The science of chemistry deals with the nature of matter, its properties, and changes it undergoes.
- Chemical reactions are often accompanied by observable changes, such as precipitation, the evolution of a gas, a change in color, and a change in temperature.
- Materials can be classified on the basis of their similarities and differences. A classification scheme is judged by its usefulness; different classification schemes are possible for a given set of materials.

MEASURING MATTER

- Weight and mass are two related, but distinctive, ways of expressing the quantity of matter in a sample.
- Physical properties can be measured; these measurements are expressed in science by numbers and metric (SI) units.
- Regularities or trends in data can be shown in graphs of the data.

INVESTIGATING PHYSICAL PROPERTIES

- Matter is composed of mixtures and pure substances. Mixtures can be separated into pure substances.
- Pure substances can be classified as either compounds or elements.
- Mass percent is a convenient way to express the composition of a mixture.
- Pure substances can be identified by well-defined physical and chemical properties; mixtures exhibit a range of values for each property.
- Chemists have many different laboratory techniques and methods at their disposal for separating and identifying materials.
- A combination of properties is often necessary to identify an unknown substance.

MATTER IN MOTION

- Models or theories are used in science to explain observed behavior. Their usefulness is partly judged on their ability to predict future behavior correctly.
- The kinetic molecular theory is a useful model to explain observed differences in physical state (solid, liquid, gas) based on molecular motion.
- There is a trend from order to disorder as the motions of molecules increase and phase changes occur.

CHEMICAL CHANGES

- Synthesis and analysis are two important approaches to learning about matter.
- Mass is conserved in chemical reactions.
- Chemical reactions can be usefully represented by topic.
- Elements combine to form compounds in definite mass ratios.
- Chemicals "consumed" in a reaction can sometimes be recovered by recycling.

THE STRUCTURE OF ATOMS

- An atom is composed of a nucleus containing protons and neutrons, surrounded by electrons. The atom's mass is concentrated in the nucleus.
- Atoms of the same element may have different masses, depending on the number of neutrons in the nucleus.
- All atoms of a given element contain the same characteristic number of protons. This number is called the atomic number.

THE LANGUAGE OF CHEMISTRY

- IUPAC rules provide consistent, internationally accepted procedures for naming compounds.
- Properly written chemical equations represent what is known about actual chemical reactions.
- Conservation of matter is a principle underlying the writing of balanced equations.

THE MOLE CONCEPT

- A mole, 6×10^{23} particles, is an SI unit that defines a certain amount of substance. The particles in a mole can be of any kind (e.g., atoms, molecules, ions, electrons).
- The molar mass of a substance represents the mass (in grams) of one mole of that substance. The molar mass of a substance composed of molecules is sometimes called the molecular mass.
- Chemical equations can be interpreted in terms of the relative number of atoms, molecules, or moles of reactants and products, or in terms of the masses of these substances.
- The concentration of a solution can be expressed as the number of moles of solute per liter (dm^3) of solution, termed the molar concentration (molarity).

CHEMICAL BONDING

- The energy needed to remove an electron from an isolated atom is called the ionization energy. Each element has a unique and different ionization energy.
- The arrangement of elements according to their periodic properties is called the *Periodic Table of the Elements;* this arrangement helps chemists to organize their knowledge about the elements.
- An ion is formed when an atom or group of atoms either gains electrons or loses electrons.
- A molecule or complex ion is formed when electrons are shared by atoms.
- Electrons in an atom are arranged in distinct energy levels, or shells, around the nucleus.
- The chemical behavior of an element is determined in part by the number of outer-shell, or valence, electrons present.
- Atoms that lose electrons are oxidized; atoms that gain electrons are reduced. These terms apply whether the gain and loss are real or only apparent.
- Chemical bonding can be largely interpreted on the basis of the transferring or sharing of electrons to attain stable octets in many compounds.
- Chemical reactions involve the forming and breaking of bonds.

SHAPES OF MOLECULES

- The arrangement of valence electron pairs in three-dimensional space determines the shape and reactivity of a compound.
- Partial electronic charges help explain the behavior of a class of substances called polar molecules.
- Because of its polar nature, water forms hydrogen bonds that help account for some of its specific properties.

Module Objectives

We have attempted to group module objectives in three broad categories: concept-centered, attitude-centered, and skill-centered. The categories are not mutually exclusive; there is considerable overlap. The conditions for accomplishing each objective are not given, since they can easily be found in the respective section in the module. Note also that concept and skill objectives are more specific than those in the affective domain. It is very difficult to classify objectives in this way, but we have been encouraged to do so by classroom teachers who have helped in this difficult task.

The objectives identified here should provide you with a useful starting point in clarifying your own goals in teaching this module. We encourage you to identify alternate objectives, using this list as a point of departure. Assessment items can be found at the end of major sections in the student module in the form of *Questions, Problems,* and *Exercises.* Other *Evaluation Items* are included after each major section of this guide and in the form of module tests for knowledge and skill objectives, located in the *Teacher's Guide* appendix.

Concept-Centered Objectives	*Attitude-Centered Objectives*	*Skill-Centered Objectives*
	CHEMISTRY: A HUMAN ACTIVITY	
A-2 ● Distinguish between observation and interpretation. ● Identify observations that can indicate that a reaction has occurred between two substances. **A-4** ● Devise a classification scheme for any given set of materials.	● Show awareness of the everyday importance of chemistry. ● Report laboratory observations carefully and honestly. ● Defend observations in light of opposition.	**A-2** ● Observe physical and chemical phenomena and accurately report observations. ● Distinguish reactive from nonreactive materials. **A-3** ● Classify a number of materials according to stated guidelines.
	MEASURING MATTER	
A-5 ● Explain the difference between mass and weight. **A-7** ● Determine the nature of the relationship between mass and volume from a graph of paired mass-volume values. **A-8** ● Apply dimensional analysis to simple metric conversion problems.	● Share opinions and ideas in class discussions. ● Recognize the importance of an international system of measurement. ● Show awareness of the worldwide trend toward adoption of the modernized metric system.	**A-6, 7** ● Measure the mass and volume of a solid object, reporting both values to the precision of the respective instruments used. ● Attach units to measured data. ● Construct a graph from data containing paired values (i.e., mass-volume). ● Read mass or volume data from a graph of paired values. **A-8** ● Use metric units to report laboratory measurements.

Concept-Centered Objectives	Attitude-Centered Objectives	Skill-Centered Objectives
INVESTIGATING PHYSICAL PROPERTIES		
A-9 ● Distinguish between pure substances (elements and compounds) and mixtures. ● Calculate the mass percent of a mixture. **A-10, 11** ● Devise a scheme for separating a two-component mixture. **A-12** ● Cite examples of typical physical properties. ● Identify evidence for physical changes. **A-13** ● Determine the density of a substance from a mass-volume graph, or from direct mass-volume measurements, and express the density in correct units. ● Formulate an explanation for deviations between laboratory results and accepted values. ● Interpret the physical changes associated with the plateaus in graphs of warming and cooling data.	● Recognize the importance of objective, unbiased observations in science. ● Seek explanations for chemical and physical changes observed in the laboratory. ● Explain how scientific and technological progress are basic to the advancement of human welfare. ● Interact with teacher and classmates in comparing and interpreting data.	**A-10, 11** ● Separate the components of a mixture, using processes appropriate to the mixture, such as dissolving, subliming, filtering. ● Calculate the mass percentage composition of a mixture from measured values. ● Determine the relative solubility of a substance in various solvents and at different temperatures. **A-13** ● Calculate density of solids and pure liquids. ● Determine freezing and boiling points of pure liquids and mixtures. **A-15** ● Identify an unknown substance, given physical properties such as density, freezing (melting) point, and boiling point, and a table of values for a number of substances. ● Use *Table of Physical Properties* or *Handbook of Chemistry and Physics* to compare student and accepted values. ● Graph and interpret data.
MATTER IN MOTION		
A-16, 17, 18 ● Describe or recognize features of the kinetic molecular theory. ● Account for the observable physical properties of solids, liquids, and gases by means of the kinetic molecular theory. ● Explain changes of state from solid to liquid to gas in terms of the kinetic molecular theory. **A-19** ● Identify the pattern upon which specific models are built.	● Judge the value of a theory or model in terms of its ability to account for observations and to predict future behavior.	**A-19** ● Devise a sequence of terms based on a certain pattern or module.

CHEMICAL CHANGES

A-20
- Distinguish between chemical analysis and synthesis.

A-21
- Recognize evidence for chemical change.

A-22
- Illustrate, with suitable word equations, the steps involved in the recycling of a substance.
- Classify chemical reactions by type from among oxidation-reduction, neutralization, and precipitation.

A-23
- Determine the relative masses of the elements in a binary compound, given data similar to those in this experiment.

- Practice cautious and safe laboratory procedures.

A-21
- Initiate a chemical reaction between two specified elements and examine the properties of reactants and products.

A-22
- Synthesize chemical compounds.
- Demonstrate decanting, removal of moisture from a precipitate, and dissolving a precipitate.
- Classify a solution as either acidic, basic, or neutral, given the solution and pH or litmus paper.
- Write word and symbolic equations.

A-23
- Calculate the mass ratio of elements in a binary compound after separating them.

THE STRUCTURE OF ATOMS

A-25
- State or recognize the basic ideas of Dalton's atomic theory.
- Explain how the relative masses of atoms can be determined.

A-26
- Compare the three fundamental particles of the atom in terms of relative masses, charges, and location.
- Distinguish between mass number and atomic number.

A-27
- Recognize the characteristics that distinguish two different atoms as isotopes of the same element.
- Cite examples of isotopes.

A-28
- Compare the size of the nucleus with the size of the atom.

- Challenge Dalton's theory in terms of more recent knowledge or personal ideas.
- Feel some of the frustration of trying to describe and measure units too small to be seen.
- Sense that chemistry (and science generally) is an "unfinished business" with many discoveries and answers yet to be uncovered.
- Recognize the limitations of science as well as its successes.

A-25
- Predict the atomic mass of one element, given the relative mass ratio between two elements and the atomic mass of the second element.

A-26
- Determine the number of protons, neutrons, electrons, mass number, atomic number, name, and/or symbol for any given atom.

A-27
- Calculate the average atomic mass or relative abundances of isotopes of an element, given appropriate data.

A-28
- Calculate the relative volume of the atom and its nucleus, given appropriate data.

Concept-Centered Objectives	*Attitude-Centered Objectives*	*Skill-Centered Objectives*
	THE LANGUAGE OF CHEMISTRY	
A-29, 30 • Distinguish an ion from a neutrally charged atom. • Determine formulas of compounds given in the tables of common positive and negative ions. **A-31** • Interpret a balanced equation in terms of conservation of atoms (mass). **A-32** • Write balanced equations for reactions expressed in sentence form.	• Understand that chemical names and equations are systems designed to facilitate communication about the world. • Recognize the importance of an international system for nomenclature.	**A-29, 30** • Name simple compounds by the IUPAC system. • Write formulas for simple ionic compounds. • Name or write formulas for compounds containing radicals, given the tables of common positive and negative ions. **A-31** • Determine the number of atoms of each element present in one unit or molecule. • Write balanced equations for reactions stated in symbolic or sentence form. **A-32** • Synthesize H_2, O_2, and CO_2 gas. • Write balanced equations for synthesis of H_2, O_2, and CO_2.
	THE MOLE CONCEPT	
A-33 • Explain how large numbers of uniform particles can be counted by weighing. **A-34, 35, 36** • Relate the number of items in a collection to the mass of the collection. • Determine the mass of one mole of an element or compound. • Identify the number of particles associated with one mole. • Relate one mole of a substance to 6.02×10^{23} particles of that substance. • Interpret a chemical equation in terms of molecules, atoms, ions, moles, and/or grams.	• Recognize the influence of science in all phases of modern life. • Weigh all available evidence in making a judgment or conclusion.	**A-33** • Use weighing techniques to determine the number of particles in a large set of uniform particles. **A-34, 35, 36** • Demonstrate dimensional analysis in doing mole calculations. • Calculate the molar mass of a compound, given the formula. • Calculate the number of moles of a substance, given the mass of the substance in grams. • Calculate the mass of a substance in grams, given the number of moles of the substance.

Concept-Centered Objectives	*Attitude-Centered Objectives*	*Skill-Centered Objectives*
A-37 ● Analyze the mole/mass relationships in a reaction. ● Relate mole/mass of reactants used to mole/mass of products formed. ● Relate molarity (as a unit of concentration) to the moles-per-liter of a solution.		**A-37** ● Calculate the molar concentration (molarity) of a solution, given the volume of the solution and the amount of dissolved solute.
	CHEMICAL BONDING	
A-38 ● Describe the process of ionization and the meaning of ionization energy. ● Identify families and periods in the periodic table. ● Describe the energy level, or shell, model for electron arrangement. **A-39** ● Describe valence shells and valence electrons. **A-40, 41** ● Identify examples of oxidation and reduction. ● Distinguish between ionic and covalent compounds. ● Explain ionic or covalent bonds by electron transfer or sharing.	● Exchange ideas with others. ● Consider ideas that are different from one's own.	**A-39, 40** ● Use the octet rule to predict stable structures (ionic or molecular). ● Write electron-dot structures for simple ions and neutral atoms. ● Write electron-dot structures for compounds.
	SHAPES OF MOLECULES	
A-43 ● Distinguish bonding from nonbonding electron pairs, given an electron-dot structure. ● Predict the shapes of simple radicals or molecules. **A-45** ● Cite examples of polar molecules. ● Relate polarity of molecules and hydrogen bonding of H_2O molecules to solubility of ionic compounds.	● Find pleasure in the activities of chemistry, such as doing experiments and constructing models. ● Elect to continue the study of other IAC modules.	**A-43, 44** ● Construct a model for the positions of four electron pairs located about a central atom in three-dimensional space. ● Construct models of simple molecules. ● Estimate or measure bond angles from models.

Teaching Reactions and Reason

Chemistry: A Human Activity

The focus of this introductory section is on some of the fundamental activities of chemistry—observing, classifying, and interpreting. The first laboratory activity, experiment *A-2 Reactions and Observations*, permits students to observe a variety of chemical changes. The experiment is also designed to emphasize to students the importance of their *own* observations, regardless of what others may report. The process of classification in the study of matter is introduced and illustrated in miniexperiment *A-4 A Place for Everything*. (Formal classification of matter will follow in later sections.) The text narrative does not require much class time in these introductory sections. Involve your students as quickly as possible in the laboratory work and remember that the module should be taught at a reasonably brisk pace.

A-1 WHY CHEMISTRY?

This section needs little amplification in class. If your first-day class schedule permits, move directly into the experiment *A-2 Reactions and Observations* at the outset. Involve your students in *doing* chemistry. This is one of the major themes of this module and of the IAC program.

Avoid a teacher-centered approach in introducing chemistry to your class. Lecture briefly, if at all. You need not discuss topics such as the scientific method, the definition of chemistry, or the purpose of the IAC program. Bear in mind that IAC should be pleasurable, interesting, student-centered, activity-oriented, and good chemistry. *First impressions are lasting impressions!*

Miniexperiment Have students make a collage of chemistry-related newspaper headlines and advertisements, similar to those found on page one of the student module. Suggest to them that they check a newspaper for at least a week in their search for headlines. Make a comparison of the students' collages and discuss the themes that are apparent.

EXPERIMENT
A-2 REACTIONS AND OBSERVATIONS

This experiment introduces the processes of observation, interpretation, and classification in the chemistry laboratory. Students independently discover that their observations do not match those of other students. The experiment thus emphasizes the importance of self-reliance and communication of results in scientific activities.

Concepts In doing this experiment, a student will encounter these important ideas:*

- Chemical reactions are often accompanied by certain observable changes, such as precipitation, evolution of a gas, a change in temperature, or a change in color.
- Chemical reactions can be classified by type; classifying often depends on more than one observation.
- Materials similar in appearance may react differently.

Objectives After completing this experiment, a student should be able to:*

- Make careful observations of reactions between two substances.
- Record accurately and completely the observations made.
- Distinguish reactive from nonreactive combinations of materials.
- Organize data.
- Classify a number of different reactions into two or more categories, based on observational data.
- Defend observations in the face of opposition—be self-reliant.
- Distinguish observations from inferences or interpretations.
- Identify at least three observations that can indicate a reaction has occurred between two substances.

Estimated Time One laboratory period (45 minutes) for a brief prelab discussion and for the experiment. One-half period or longer for your postlab discussion.

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*This statement appears only with the first experiment, but it applies each time this section appears in an experiment, unless otherwise noted.

Student Grouping Pairs

Materials* You will need the following materials for a class of 30 students working in pairs:

75 13 × 100-mm test tubes
60 dropper bottles *or*
60 50-cm^3 beakers with 1 dropper for each (use closed containers for NH_3 solution)
Two sets of chemicals, both labeled *A-E* (see **Advance Preparation**):

Set 1

(A) 250 cm^3 1 M hydrochloric acid (HCl)
(B) 250 cm^3 bromocresol green solution
(C) 250 cm^3 0.1 M potassium iodide (KI)
(D) 250 cm^3 0.1 lead nitrate [$Pb(NO_3)_2$]
(E) 30 zinc (Zn) strips (size to fit in test tubes)

Set 2

(A) 250 cm^3 1 M hydrochloric acid (HCl)
(B) 250 cm^3 0.1 M copper(II) sulfate ($CuSO_4$)
(C) 250 cm^3 0.1 M potassium iodide (KI)
(D) 250 cm^3 ammonium hydroxide [NH_4OH, $NH_3(aq)$]
(E) 30 zinc (Zn) strips (size to fit test tubes)

Pass out the two sets of reagents to your students, either in small coded beakers or dropper bottles. Place each set at a different lab bench to insure different student observations. Identify the materials only by the code letters (A, B, C, etc.). Note that *Set 1* and *Set 2* are identical except for two chemicals. *Set 2* contains copper(II) sulfate and ammonium hydroxide instead of the bromocresol green and lead nitrate solutions. *Do not* call attention to the difference in the sets at the beginning of the laboratory session. Let students assume all sets are the same.

Advance Preparation To make solutions (exact concentrations are not necessary—check before using):

1 M NH_3 Add 17 cm^3 concentrated ammonium hydroxide to 200 cm^3 distilled water. Then add enough additional distilled water to make 250 cm^3 of solution.

1 M HCl Add 42 cm^3 concentrated hydrochloric acid to 400 cm^3 distilled water. Then add enough additional distilled water to make 500 cm^3 solution.

0.1 M KI Weigh 8.5 g potassium iodide and dissolve in enough distilled water to make 500 cm^3 of solution.

0.1 M $CuSO_4$ Weigh 6.2 g copper sulfate crystals ($CuSO_4 \cdot 5H_2O$) and dissolve in enough distilled water to make 250 cm^3 of solution.

0.1 M $Pb(NO_3)_2$ Weigh 8.2 g lead nitrate and dissolve in enough distilled water to make 250 cm^3 of solution.

Bromocresol Green Solution Dissolve about 0.05 g bromocresol green in 25 cm^3 of 0.01 M sodium hydroxide (0.01 M NaOH: 0.4 g NaOH per 1000 cm^3). Add this solution by drops to 250 cm^3 distilled water until the color intensity matches that of the copper(II) sulfate solution.

Put the labels *A, B, C, D,* and *E* on small beakers or dropper bottles. Fill half the *A-E* containers with *Set 1* materials. Fill the remaining half with *Set 2* materials.

Prelab Discussion To introduce this activity, you may wish to appeal to the popular stereotype of a chemist as someone who industriously mixes chemicals and observes results in a laboratory. Suggest that this rather limited view of a chemist's work will be altered in this course, but that such activities do indeed represent a part of what it means to "do chemistry."

Briefly discuss the data table which is suggested in the student's module for recording observations. Note that the data table requires only 10 combinations, not 25, to sample all paired interactions.

Consider how you wish students to keep and use their laboratory notebooks. See the introduction to this guide for suggestions.

Instruct your students to return used metal pieces to specially labeled containers. Explain that all other liquids and materials can be flushed down the sink with tap water.

No additional prelab discussion is needed or advised. *Do not discuss at this time the fact that all the sets of chemicals which the class has used are not identical.*

Laboratory Safety Before your students actually begin their laboratory experiences, introduce them to *Appendix I: Safety* on page 92 of the student module. Briefly discuss the sections *Safety in the Laboratory* and *General Safety Guidelines*. If you have already discussed the experiment, you may wish to ask the students to pick out the guidelines that apply specifically to this situation. Point out the safety symbol at the bottom of the page and discuss why this reminder will appear at specific experiments through this and other IAC modules. For a later discussion, you might ask each

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*The *Materials* list for each laboratory experiment in this module is planned for a class of 30 students working in pairs. You may have to adjust this to fit the size of your class.

student to pick a safety guideline and explain why this represents common sense and why such guidelines are no different from other similar rules encountered in daily life.

Identify the safety features in your laboratory. Make sure all students know they are to wear protective glasses and laboratory aprons. Remind them that chemicals should never be tasted; odors should be investigated cautiously; if chemical splashes occur, skin should be washed with generous quantities of water.

Laboratory Tips During the experiment, some students may discover that their results do not completely match those obtained at a different lab bench. (This subtle student "radar" is remarkable to witness.) If such observations are made, remain reasonably noncommittal about them. Simply encourage the students to follow the original instructions and to record their observations. Some students will be mildly distressed; the pressures to be "right" at all costs are strong.

By contrast, in some classes the experiment may be carried out without any "We didn't get what they got" comments. This is equally satisfactory. The postlab discussion of student results provides the time to discover the disagreements.

Range of Results Representative student observations for each of the two sets of chemicals are shown on the two tables on the following page.

Postlab Discussion You might initially attempt to fill in one large data table on the chalkboard or overhead projector, asking students to volunteer their observations. Start with combination $A + E$, which is common to all student sets. Almost all students will agree on what they observed for this combination—bubbles formed at the surface of solid E. From this point on, however, little accord will be found.

Students may discuss the "disagreements" with considerable emotion. When things reach an impasse, you may wish to ask, "Well, who's right?" A student may suggest that the sets be rechecked. Be prepared for this challenge. Have both sets on hand for an on-the-spot demonstration where you may wish to repeat portions of the experiment. Give your students an opportunity to check their previous observations and to evaluate the conclusions that they have made. Eventually, of course, the message becomes clear—everyone is correct! Although the starting materials seemed to be the same, materials must have been involved.

Stress the importance of each individual's own observations. In a real sense there were no "wrong" *observations;* what one saw was exactly what should be seen under the circumstances. In fact, the odd, unexpected observation is often the basis for a new discovery in science, if it is made under controlled, reproducible conditions.

This is a good time to make a distinction between observations and interpretations. A student can *observe* the formation of gas bubbles, but the statement "hydrogen gas is formed" would be classified as an inference, or interpretation. The distinction is a worthwhile one to keep in mind in science, because interpretations are always subject (at least in principle) to challenge and change. All we ask is that our interpretations be useful and consistent with other ideas and with what we can observe. Observations are the "givens" in science; regardless of how theories and ideas change, the observed facts remain as before for us to ponder.

For more advanced students, it might be important to identify the chemicals used in this experiment. You might also wish to focus on one or two specific reactions (e.g., the effect of hydrochloric acid on zinc metal) to illustrate the nature of chemical change.

Discuss the types of evidence found in this experiment that lead one to assume that a chemical reaction is taking place—odor, heat effect, gas evolution, precipitate formation, color change. Suggest that these kinds of reactions will be studied repeatedly in this course.

A-3 CLASSIFYING MATTER

Treat this section as a brief prelab to miniexperiment *A-4 A Place for Everything*. The classification message here can be strengthened if students realize that a given set of materials or observations can be usefully classified in several different ways. Thus, a postage-stamp collection can be organized by country, by perforation, by water marks, by year, or by century, by shape (triangles, rectangles), or by the subject matter on the stamp (birds, historic figures, modes of transportation). One selects a particular classification scheme because it organizes the items in a useful way. Other classification methods may be equally useful under different circumstances.

Coin, autograph, button, matchbook cover, and other collections can serve as good display, discussion, or practice examples.

Set 1	A	B	C	D	E
E	Bubbles Form on Metal	No Change	No Change	Black Coating on Metal	
D	White Precipitate	No Change	Yellow Precipitate		
C	No Change	No Change			
B	Clear Yellow Solution Forms				
A					

Set 2	A	B	C	D	E
E	Bubbles Form on Metal	Black-Brown Coating on Metal	No Change	No Change	
D	Some ‘Smoke’ Seen; Odor; Mixture Gets Warm	Clear, Deep Blue Solution Forms	No Change		
C	No Change	Yellow-Brown Precipitate			
B	Clear Green Solution Forms				
A					

EXPERIMENT A-2, RANGE OF RESULTS

Miniexperiment *Classification:* Duplicate enough copies of the classification activity on guide page 13 for each of your students. Ask them to group the geometric shapes according to their own scheme. Then ask them to present their scheme in the form of a chart similar to the example that appears on page 4 of the student module.

You may wish to have some of the students put their classification scheme on the chalkboard and let the class try to decide the criteria. If the class is able to determine how the classification was done, the scheme can be considered useful.

You may wish to use this activity after miniexperiment *A-4* instead of introducing the miniexperiment with it.

MINIEXPERIMENT
A-4 A PLACE FOR EVERYTHING

This short activity invites direct student participation in classifying materials. Instruct each student to bring a small sample of something "chemical" from home. To insure a wide range of samples, keep your detailed instructions to a minimum. Discourage students from bringing toxic or hazardous materials.

You can expect your students to round up a wide variety of materials. Teachers have reported students delivering such diverse things as salt, sugar, vinegar, detergents, a match, soy sauce, epsom salt, baking soda, jasmine incense, shoe polish, floor wax, motor-oil additives, and a cake mix. One student turned up with a jar of peanut butter. Another student displayed a foam plastic cup.

Have the students arrange their "chemicals" on a display table. Then invite them to devise a classification scheme for organizing the wide array of samples. Call to the attention of your class the "chemical library" concept suggested in the student instructions. This concept may help students focus their thought on the classification problem.

From experience, students will suggest some obvious systems of classification. Someone may propose that the samples be classified according to color, size, and general use. A more sophisticated individual may propose a classification based on hardness, texture, composition (metals, plastics, glass), or state (solid, liquid, gas). Others in the class may refer to density, solubility, transparency vs. opacity, or natural vs. synthetic as a basis for classification.

Emphasize that there are many different ways of classifying or organizing the samples. The test of a particular scheme is simply utility! Later in this module we will focus on several specific properties of substances which permit useful classification of materials: density, solubility, boiling point, freezing point.

Miniexperiment Have your students suggest a useful classification scheme for one of the following groups of items: magazines, automobiles, stereo records, Olympic sports events, geometric figures.

Miniexperiment *Beetle Analysis:* Duplicate enough copies of the *Flowchart for Qualitative Beetle Analysis,** which appears on guide page 14, for each of your students. Base a class discussion on how classification principles can be applied to many practical problems—including the determination of the production year of a given VW Beetle.† Perceptive students may wish to extend the flowchart to models newer than 1974, the last year summarized in this chart.

ANSWERS TO QUESTIONS

(Student module page 5)

1. Variety of answers possible here.
2. Many answers possible here, as well.
3. Six chemicals require 15 combinations; 10 chemicals require 45 combinations.
4. Students should suggest classifications based on physical appearance, sex, clothing, age, etc.

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*Reprinted with permission from *Chemistry,* Vol. 48, No. 4, April 1975. Copyright by the American Chemical Society.

†Note that it is not our intention to endorse or recommend any product illustrated in the IAC program. Many references similar to this are used to illustrate the application of chemistry to situations in everyday life.

Miniexperiment *Classification:* Classify these geometric objects according to a scheme of your own choosing. Present your classification in the form of a chart similar to the example found on page 4 of the student module.

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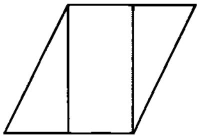

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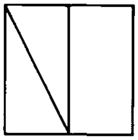

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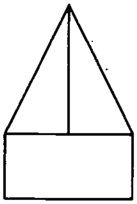

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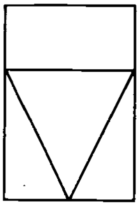

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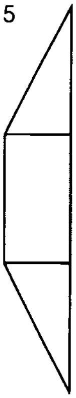

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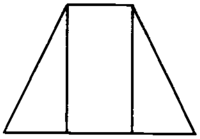

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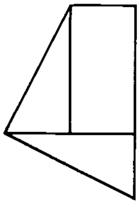

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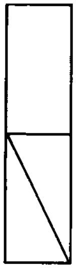

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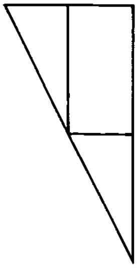

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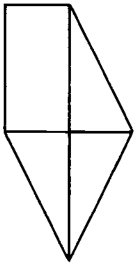

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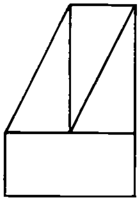

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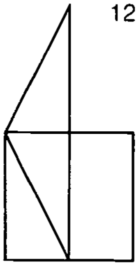
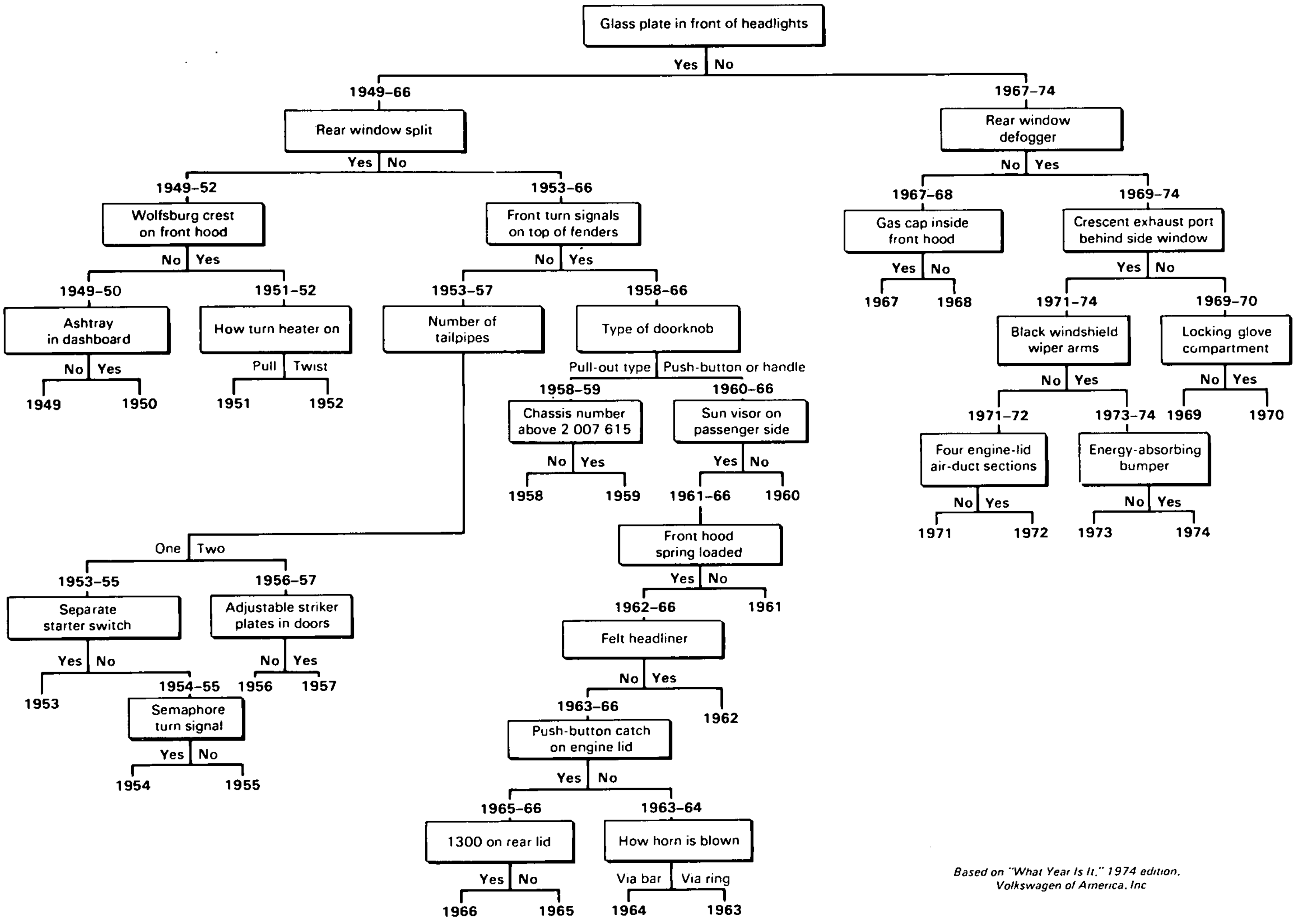


Flowchart for Qualitative Beetle Analysis

H. Heikkinen, University of Maryland, College Park, MD 20742

(Instructions: work from top down)



Based on "What Year Is It," 1974 edition. Volkswagen of America, Inc

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. A student mixes two clear, colorless liquids together in a test tube. Which of the following statements is an interpretation rather than an observation?
   A. The test tube feels warmer after the solutions are mixed.
   B. The resulting mixture is clear and colorless.
   C. Ammonia gas is given off when the liquids are mixed.
   D. Wavy lines can be seen in the test tube when the two liquids are first poured.
2. A student has mixed two chemicals together. Which of the following would not be accepted as evidence that a chemical reaction has occurred?
   A. A temperature change has been observed.
   B. A boundary has formed between the two chemicals.
   C. A precipitate has formed.
   D. A gas has been given off.
3. Imagine that Noah's son, Shem, was entrusted with the supervision and care of a group of animals in the ark's below-deck quarters. There were two of every kind of animal, male and female: elephant, zebra, crow, and rabbit. Noah's son realized immediately that his section of the ark would be a free-for-all zoo unless he organized the animals and established some kind of order. Suggest possible ways he could have done this.
4. Construct a schematic flowchart to classify coins (or stamps, dogs, motorcycles, etc.).

Measuring Matter

In this section, your students encounter ideas related to scientific measurement. They are called upon to develop an understanding of the modern metric system through a study of SI units. Volume and mass are developed as two specific physical properties of materials through measurement-oriented laboratory activities. (These data will support the concept of density that is introduced later in the module.) The text stresses graphing as a means of identifying and reporting a relationship between two numerical properties.

A-5 MASS OR WEIGHT?

A *brief* weight-mass discussion is useful here to suggest differences as well as similarities in the meaning of these two terms. Since we conduct our course work in a fixed, earth-bound laboratory, either mass or weight can be a useful expression of the relative quantity of matter present in a sample. We will favor mass in IAC modules whenever it seems reasonable in context. Students will still *weigh* their samples but we will speak of atomic masses and molar masses.

Introduce the distinction between mass and weight in an informal, reasonable manner. This is not an appropriate place to insist on a rigid, technical definition of each term. Success in this course will not hinge on a precise distinction between mass and weight!

In modernized metric (SI), weight is regarded as a force. Thus the appropriate SI unit for weight is the newton (N), as is briefly discussed in Appendix II of the student module. The kilogram and its multiples and submultiples are properly used as mass units in the modernized metric system.

A-6 VOLUME: A SPACE FOR EVERYTHING

This section introduces the volume-measuring techniques that students will apply in experiment *A-7 Mass and Volume*. Thus, the section can serve as a prelab presentation. Stress the importance of attaching units to the numbers used in measurement (2 couples, 1 herd, 1 year, 1 baseball team). Note that this idea is treated in greater detail in section *A-8 Let's Go Metric!* (Note: The answer to the question about the volume of Figure B is 80 cm^3.)

Refer in the text to the explanation of how the volume of an irregularly shaped object can be measured by means of water displacement. Have two students demonstrate the water-displacement method by measuring the volume of a small stone or other handy object. This will prepare the class for the experiment that follows. Point out how the liquid meniscus is read. Stress the importance of reading a scale to the limit of its precision.

Answers to the three problems appearing on page 8 are given below. (You will need to decide whether skills related to significant figures and rounding off should be introduced at this point or later. We make reference to these skills for the first time in section *A-9* of the module. Appendix IV contains the appropriate background, in any event.)

1. $V = lwh = (9.5\text{ cm})(13\text{ cm})(31\text{ cm})$
   $= 3828.5\text{ cm}^3 = 3800\text{ cm}^3$
2. $V = \pi r^2 h = (3.14)(3.2\text{ cm})^2(12\text{ cm})$
   $= 385.8432\text{ cm}^3 = 390\text{ cm}^3$ (Students who use pocket calculators with a "π" key will obtain a readout of $386.038\,905\,3\text{ cm}^3$, which still rounds to 390 cm^3.)
3. Volume of two stones $= 48.0\text{ cm}^3 - 32.0\text{ cm}^3$
   $= 16.0\text{ cm}^3$

Miniexperiment Invite students to measure the volumes of familiar objects. Suggest that they measure the volume of the classroom, a textbook, or a laboratory bench. How could the volume of a person be measured?

Miniexperiment The shape of a container sometimes influences our judgment of the actual volume of material which the container can hold. Collect a variety of home containers (mustard jar, shampoo bottle, catsup bottle, pickle jar, soft-drink bottle). Investigate which shapes *appear* to hold more liquid than they actually do by having someone judge the bottles and arrange them in order of estimated increasing volume (assuming that all volume information on the labels is covered up). Then check the actual volumes.

EXPERIMENT
A-7 MASS AND VOLUME

The purpose of this experiment is to develop the student's skill in measuring mass and volume. The experiment also introduces several common SI units of measurement. From the data collected, students can establish a mass-volume relationship for different materials. The concept of density is developed later from these data in section *A-12 Physical Properties and Changes*.

Concepts

- The volume of irregularly shaped objects can be determined by fluid displacement.
- Physical quantities are properly expressed and identified by the use of numbers and units.
- Regularities or trends in observed data can be visually identified from a graphical presentation of the data.
- There is a straight-line relationship between the mass and volume of any size sample of a given substance when these measurements are plotted on a mass-volume graph.

Objectives

- Measure the mass and volume of a solid object, reporting both values to the precision of the respective instruments used.
- Construct a graph from data containing paired values (i.e., mass-volume).
- Attach metric units to the data collected.

Estimated Time Half-period of prelab discussion; one period for lab activity; half-period for postlab discussion.

Student Grouping Pairs

Materials

balances (0.1 g to 0.01 g sensitivity)
graduated cylinders of varying sizes (10 cm³, 25 cm³, 50 cm³, 100 cm³)
250-g samples of three of the following or similar materials:
  copper shot
  glass beads or marbles
  iron nails
  lead shot
  aluminum nuts and bolts
  brass fittings
  solid rubber stoppers, #00 to #6 sizes

Advance Preparation Obtain three of the materials listed above for use in this experiment. Every pair of students uses the same three materials. Do not select both lead shot and copper shot samples for the same laboratory because they tend to become mixed. Try to select three substances which represent discernible differences in density—rubber stoppers, glass marbles, and iron nails would be a representative set, for example.

Prelab Discussion Demonstrate the operation of the balances available in your laboratory. Allow students to practice weighing assorted objects. Introduce or review metric units for mass and volume. Consistent with SI usage, we will routinely express volumes in cubic centimeters (cm^3) rather than milliliters (ml). These two units are exactly equal to each other.

In the United States the recommended symbol for liter is now L. There is still some debate as to whether the symbol should be a capital L, a lowercase l, (as SI still defines it) or perhaps a script ℓ. There are advantages to the use of the capital L, since it cannot be mistaken for the numeral one. At this time, we have chosen to spell out the term when it is used in the student module. In your classroom, you may wish to have your students use an abbreviated form for liter. It is for you to decide.

Show the proper method for reading a liquid meniscus (to small groups of students at a time), or quickly review the method if your students have had this experience before.

Assign each pair of students one of the following sample masses for each of the three materials: either 5 g, 10 g, or 15 g (i.e., *pair 1* works with 5-g samples, *pair 2* uses 10-g samples, etc.). Suggest that students use the smallest graduated cylinder convenient for their sample size. You might ask students to bring in some of the substances to be used (e.g., aluminum or brass hardware). The only restriction is that the material should come in relatively small "pieces" so that the assigned 5-, 10-, or 15-g quantities can be weighed and placed in the cylinders provided.

Do not introduce the concept of density at this point. This will develop naturally from the data collected later in section *A-12*. If they recall their past work in science, the students in your class will be able to explain density before proceeding with the sections which follow. But every student probably will benefit from a review of the concept.

Laboratory Tips It may be necessary to tap the graduated cylinder to remove air bubbles clinging to the surface of the material before liquid volumes are measured. It may not be possible to obtain exact 5-, 10-, or 15-gram samples of some materials. Instruct your students to record and report the actual masses of each substance taken.

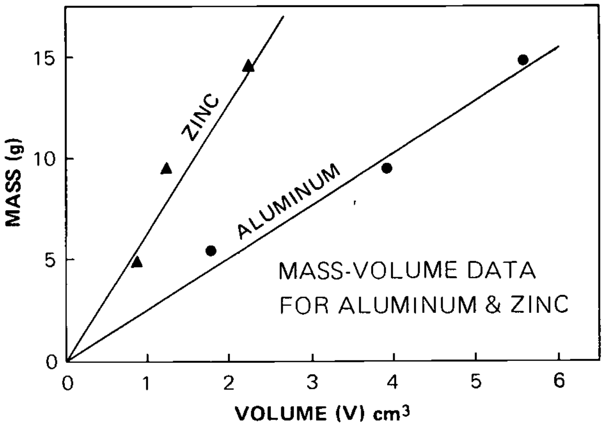
Mass-volume data for all three substances should be entered on the chalkboard by students as they finish. Students will need to record in their notebooks all mass-volume data obtained to prepare their graphs.

Ask students to dry materials before returning them to the storage container.

Range of Results Students will need some guidance in preparing their mass-volume graphs. Point out some of the elements of a properly constructed graph:

- Both axes labeled with the property measured and the units used.
- The graph scales consistent; each square carrying the same value across each axis.
- Points easily identified by enclosing in circles, squares, triangles, or other coded forms.
- The graph titled.
- Independent versus dependent variables and their locations on the axes can also be discussed.

The following graph of sample data illustrates these features.



Be sure students consider the origin (0, 0) as one of the points to be included in drawing each line (slope) on their graphs.

Postlab Discussion Point out that, despite some scatter of the plotted points, the mass-volume graphs prepared by students do show that each substance is represented by a characteristic "line." An advanced class may be prepared to express equations for the straight lines, noting that the lines pass through the origin. (The equations will be of the form $y = mx$; for aluminum, the equation would be $M = 2.7V$, where V is the volume in cm^3 and M the mass of the aluminum sample in grams.) Regardless of the mathematics, all students can appreciate that the graph represents general *trends* found in the combined class data. This activity provides a simple introduction to graphing data and reading graphs.

Unless students push toward the concept themselves, do not extract the density idea at this point. The concept of density fits more naturally in your subsequent study of section *A-12*. If students do recognize density here from earlier experiences in science classes, congratulate them for their insight.

Miniexperiment To emphasize that a graph helps to identify a general trend, ask interested students to plot the number of pages in the daily newspaper in comparison with the day of the week. Have this information collected for several weeks. Some students may wish to propose an interpretation of the results. Can the interpretation be tested?

A-8 LET'S GO METRIC!

This is a brief, informal introduction to the modern metric system, identified formally as Le Système International d'Unités, or "SI" for short. Additional information on SI will be found in Appendix II of the student module. Do not dwell on cataloging formal English-metric conversion factors. Instead, fill a 1000-cm^3 beaker or a 1000-cm^3 graduated cylinder with water. Then pour the water from the beaker or graduated cylinder into a quart jar. The students will observe that the volume is slightly more than the volume of one quart. (One quart equals 946 cm^3.) A quick demonstration such as this has more impact and conveys the meaning of metric units much more clearly to students than does a table of comparative English-metric equivalents.

The mole was formally adopted in 1971 as one of the seven fundamental units of the modernized metric system, as the table in the student text suggests. Assure students that this term will be explored in detail later in this module.

SI rules suggest that the liter (also spelled litre) be used only for low-precision volume specifications. The equivalent (but more precisely defined) cubic decimeter (dm^3)—1000 cm^3—is preferred in SI usage. We have elected to use many SI units in this course, consistent with the worldwide trend toward this system of measurement. Since the United States is officially moving toward adoption of SI, we will need to keep abreast of the correct metric usage in our chemistry teaching.

The most authoritative source of information on SI in English is *The International System of Units (SI)*, issued as NBS Publication 330 by the U.S. Department of Commerce, National Bureau of Standards. This inexpensive booklet, available from the U.S. Government Printing Office, contains translations of all International Bureau of Weights and Measures resolutions concerning SI and earlier metric-based units. It is too technical for student use, but you may find it of value as a reference.

Review with your students the *Time Machine*, "The Metric System," on page 10 of the student module. You may wish to challenge some of your students to look into the history of the metric system and add any additional entries they find. Perhaps some of them might wish to find out more details about some of the events already listed. Other suggested research topics might include the discussion of the pros and cons of going metric in the United States, or the replacement of Krypton-86 as the standard for the meter. Some of your students might wish to add to the humorous caption at the top of page 13 by finding more nonmetric language that will be with us long after we are immersed in the metric system. Ask your students to bring in any metric cartoons they can find to add to a classroom display or collection.

Answers to the problems appearing in this section of the module follow. We would also encourage you to continue to highlight the dimensional analysis "message" contained in problems such as these.

1. $0.66\,\cancel{\text{m}}\left(\frac{100\text{ cm}}{1\,\cancel{\text{m}}}\right) = 66\text{ cm}$

2. $6.8\,\cancel{\text{mg Pt}}\left(\frac{0.001\text{ g Pt}}{\cancel{1\text{ mg Pt}}}\right) = 0.0068\text{ g Pt}$

3. For comparison, convert all expressions to grams

   (a) 2.20 g zinc (given)

   (b) $0.022\,\cancel{\text{kg zinc}}\left(\frac{1000\text{ g zinc}}{1\,\cancel{\text{kg zinc}}}\right) = 22\text{ g zinc}$

   (c) $220\,\cancel{\text{mg zinc}}\left(\frac{0.001\text{ g zinc}}{1\,\cancel{\text{mg zinc}}}\right) = 0.22\text{ g zinc}$

   Thus, sample (b) contains the largest amount of zinc, and sample (c) contains the smallest amount of zinc.

Miniexperiment *Metric Packaging:* Invite students to check cans, bottles, and boxes in their kitchens to see how many labels already include metric units. Ask students to estimate, from observation, the percent of grocery packages in the United States that now carry metric information. You may wish to have them make a collection of labels or empty cartons to demonstrate the extent of metric change.

ANSWERS TO QUESTIONS

(Student module page 13)

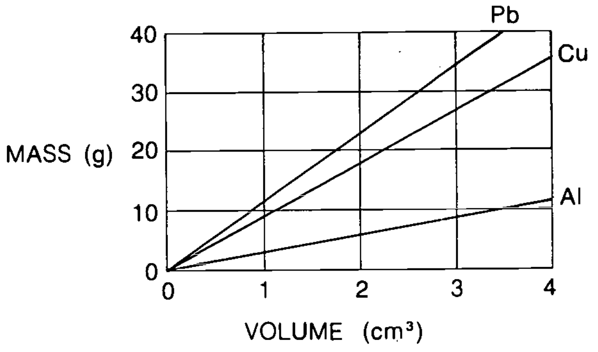
1. Weight loss will not guarantee better-fitting clothes, since the overweight person could be "weightless" in outer space and yet remain in discomfort with tight clothes. Scientifically, *mass* loss would be desired.
2. $V = L^3 = (2.40\text{ cm})^3 = 13.8\text{ cm}^3$

   $D = \frac{M}{V} = \frac{112\text{ g}}{13.8\text{ cm}^3} = 8.12\text{ g/cm}^3$
3. (a) kilogram, kg; (b) meter, m; (c) second, s; (d) cubic meter, m^3.
4. Accept a variety of responses to this item.
5. 2.937 g
6. The unknown object is iron.
7. A 15.24-cm specification implies that rods shorter than, say, 15.23 cm or longer than 15.25 cm would be unacceptable. This is a more difficult length tolerance to meet than the ±0.5 inches implied by a "6-inch" dimension. The stirring rods should be called 15-cm rods to avoid this confusion.
8. 15 lengths, since 15 × 0.24 m = 3.6 m.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

The results of a mass-volume experiment were plotted, and the following graph was obtained:



1. What volume will be occupied by 20.0 g copper?

   A. 2.2 cm³ B. 1.8 cm³ C. 3.8 cm³ D. 2.7 cm³
2. A total of 31.5 g of an unknown solid was found to displace a volume of 3.5 cm³ in a graduated cylinder. The unknown could be:

   A. Pb B. Cu C. Al
3. Which weighs more, a kilogram of feathers or a kilogram of lead? Which sample has the larger volume?

   Both have equal weight. The feathers have a larger volume.

Investigating Physical Properties

Representative physical properties (density, solubility, boiling point, freezing point) are introduced in this section. The experiments illustrate that such physical properties are useful in the processes of separating, classifying, and identifying pure substances. Students are involved in first-hand experiences with all three of these common processes.

A-9 PURE SUBSTANCE OR MIXTURE?

This section serves as an introduction to experiment *A-10 Investigating a Simple Mixture.* The meaning of a mixture will become clear to your students through the laboratory activity that follows. Much more will be said about elements and compounds later; the terms are merely introduced at this point.

Decide whether you would like your students to spend additional time with significant figures and rounding off at this point in the course. If so, have students spend time reviewing Appendix IV at the end of the student module.

Here are answers to the two mass percent problems given in this section. Student practice with problems such as these should make the calculations in experiment *A-10* relatively easy to cover.

1. $$\%\ \text{sand} = \frac{124\ \text{g sand}}{124\ \text{g sand} + 305\ \text{g sawdust}} \times 100 = 28.9\%\ \text{sand}$$

   $$\%\ \text{sawdust} = 100\% - 28.9\%\ \text{sand} = 71.1\%\ \text{sawdust}$$

2. $$\%\ \text{red fescue} = \frac{2.80\ \text{kg red fescue}}{5.00\ \text{kg total}} \times 100 = 56.0\%\ \text{red fescue}$$

   $$\%\ \text{bent grass} = \frac{1.20\ \text{kg bent grass}}{5.00\ \text{kg total}} \times 100 = 24.0\%\ \text{bent grass}$$

   $$\text{mass bluegrass} = 5.00\ \text{kg total} - (2.80\ \text{kg} + 1.20\ \text{kg}) = 1.00\ \text{kg}$$

   $$\%\ \text{bluegrass} = \frac{1.00\ \text{kg bluegrass}}{5.00\ \text{kg total}} \times 100 = 20.0\%\ \text{bluegrass}$$

EXPERIMENT
A-10 INVESTIGATING A SIMPLE MIXTURE

The purpose of this experiment is to separate a mixture by means of differences in physical properties, and to calculate the percentage composition of the mixture.

Concepts

- Mixtures can be separated into pure substances.
- Mass percentage is a convenient way to express the composition of a mixture.

Objectives

- Calculate the mass percentage composition of a mixture.
- State the characteristics that permit a sample to be classified as a mixture.

Estimated Time One period

Student Grouping Pairs

Materials

100 g iron (Fe), powder
100 g sulfur (S), flowers (powder)
15 magnets
15 magnifying glasses
plastic wrap or bags

Advance Preparation Blend the iron powder and sulfur into a uniform mixture. Be sure they are *completely* mixed. Crush any sulfur lumps which may remain. Each pair of students will need a mixture sample of about 5 to 10 grams. You can save the mixture for reuse the next time you teach this module.

Prelab Discussion Briefly review percentage composition and illustrate with a sample calculation. You can base a sample problem on a mixture of sugar and salt. Assume 20 g salt are mixed with 30 g sugar. Ask students to calculate the percentage composition of the mixture.

Suggest to your students that they wrap a piece of plastic wrap or a plastic bag around the magnet. The magnet will attract the iron filings through the material, but with the plastic as a shield, the magnet remains clean, and the filings can easily be removed.

Caution: *Instruct your students never to place any chemicals directly on the balance pan. Each sample should be placed on a piece of paper or watch glass, thus protecting the pan.* Students should first weigh the paper or watch glass. When the sample is added, they can determine the combined mass of the sample and the paper or watch glass. Subtracting the mass of the paper or watch glass from the combined mass gives the mass of the sample.

Provide a container in which students can dump their used mixture after finishing the experiment. Label containers differently if more than one kind of mixture is used. This can be mixed back into the original iron-sulfur mixture and used again.

Laboratory Tips The procedure should pose no problems. Circulate and offer help to those students who have questions. You may need to assist some of the students in starting their calculations.

Range of Results Sample data and calculations:

mass of mixture:
6.66 g (sample + paper)
− 0.92 g (paper)
5.74 g sample

mass of black powder:
3.85 g (powder + paper)
− 0.90 g (paper)
2.95 g black powder

$$\% \text{ black powder} = \frac{2.95 \text{ g}}{5.74 \text{ g}} \times 100 = 51.5\%$$

% yellow powder = 100% − 51.5% = 48.5%

The percent compositions could also be calculated on the basis of the mass of the yellow powder. As the student module explains, either of the two materials that are a part of the mixture can be weighed to determine the percent compositions of both.

Individual student results will vary by as much as 10 percent, depending on how stratified the original mixture was and how carefully the students completed the separation. However, grouped class results will permit the determination of a "best" answer for the composition of the mixture.

Postlab Discussion If you haven't already done so, identify the two separated components as iron and sulfur. Have students compare their calculated percent compositions. Discuss reasons for differences in the reported percentages. Also be prepared to discuss why the percentages do not total 100 if both components are weighed and their percent compositions calculated. The reason might be loss of sulfur or iron, or addition of moisture, for instance.

Use the class data to illustrate the idea of a mean and a median to represent overall results. Students can help in determining each value. Explain that the *mean* is an average; it is obtained by dividing the number of results into the sum of all percentages. The *median* is the middle result.

More advanced students may be interested in calculating the *average deviation* associated with the mean. In this case, encourage these students to seek the definition and means of calculating this value, and, perhaps, the *standard deviation* as well.

Miniexperiment Ask your students if they can identify other methods that can be used to separate mixtures. Then ask them how they would separate each of the following mixtures.

a. a mixture of aluminum filings and sawdust
b. a mixture of salt and sand

Ask interested students to prepare each mixture and see if their ideas work.

EXPERIMENT
A-11 PROPERTIES AND SEPARATION

This experiment extends the separation-of-mixtures idea introduced in experiment *A-10 Investigating a Simple Mixture* to more challenging systems involving new laboratory techniques. After determining some characteristic properties of four pure substances, students will attempt to identify the pair of substances present in an unknown mixture. They then will separate the substances and will calculate the percent composition of the mixture. You might demonstrate the I_2 sublimation yourself if you feel that the ventilation in your room is inadequate for the entire class to do the test.

Concepts

- Materials can be identified and classified by their characteristic physical properties.
- The solubility of a substance changes with a change in the temperature of the system and is different for different solvents.
- Chemists have many different laboratory techniques and methods at their disposal for analyzing materials.

Objectives

- Determine the relative solubility of a substance in various solvents.
- Devise a scheme for separating a two-component mixture, given a summary of physical properties of both components in the mixture.
- Determine the mass percent composition of a mixture.

Estimated Time Plan three laboratory periods for this experiment. Introduce the experiment with a brief prelab discussion at the start of the first period. During the first session, permit the students to proceed with the experiment through the identification of the unknown mixture. Devote the second period to the separation and to finding percentage amounts of the mixture. (Some students will need extra time if they have difficulty.) Conduct your postlab discussion during the third period.

Student Grouping Pairs

Materials

100 g sodium nitrate ($NaNO_3$)
100 g lead chloride ($PbCl_2$)
100 g silicon dioxide (SiO_2), pure sand
25 g iodine(I_2)
300 cm³ TTE (trichlorotrifluoroethane), available commercially as Freon-113 or Du Pont TF Solvent*
60 test tubes, 18 × 150 mm
15 evaporating dishes, #0
15 150-cm³ beakers
15 10-cm³ graduated cylinders
15 ring stands and rings
15 funnels
15 wire gauze
several magnifying glasses
15 can lids
15 candles
filter paper
ice

Advance Preparation From the list that follows, prepare an unknown mixture for each pair of students. Keep a record of the masses of the components in each unknown. Give each sample a code number. The total mass of each mixture should be from 4 g to 5 g. The list:

†$I_2 + PbCl_2$
†$I_2 + NaNO_3$
†$I_2 + SiO_2$
$PbCl_2 + NaNO_3$
$NaNO_3 + SiO_2$

Have a small bottle of each of the four pure substances available in the laboratory for the initial tests required in the procedure. Provide a supply of ice.

Prelab Discussion Ensure that students have a good sense of direction concerning this experiment before they start. They are to analyze a mixture that consists of two pure substances. To identify the components of the mixture, they first will investigate some of the characteristic properties of each of the four substances that might be present. To start, the students will note the physical appearance of each substance. Next, they will check solubility and sublimation tendency. Explain to students that although no substance is truly insoluble—each is at least partially soluble—the "Insoluble" (I) category here is used for those materials that do not appear to dissolve to any noticeable extent.

Since each sample contains either iodine or sodium nitrate, students will discover that at least one of the two specific separation techniques outlined in the procedure is useful. At most, however, students should undertake only one of the two separation procedures. Students are invited to devise their own separation procedure, subject to approval, if they wish.

Check the *Laboratory Tips* section for specific hints and suggestions that you may wish to pass on to students in your prelab session.

Laboratory Safety Stress safety precautions. Be sure the laboratory room is well-ventilated. Have your students wear aprons and protective glasses. Advise them to keep their faces away from any of the heated materials.

The iodine must be treated with special care and respect. Skin contact with $I_2(s)$ can cause lesions; $I_2(g)$ is intensely irritating to eyes and mucous membranes.

Give your class specific instructions for disposing of the TTE solvent. Like carbon tetrachloride, this nonpolar

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*Other nonpolar solvents can be used, but TTE is strongly recommended because of its low toxicity and nonflammability. Du Pont TF Solvent, essentially technical-grade TTE, can be purchased from some dry-cleaning supply companies.

†Use no more than 0.5 g to 0.75 g of iodine (I_2) in each mixture. Grind up the large lumps.

solvent is immiscible in water, but it is considerably less toxic than carbon tetrachloride. Provide a waste-solvent can to collect the used TTE. Follow your school's disposal policy, or seek advice from local community officials. Have methyl alcohol handy to remove small I_2 stains on skin, or 0.1 M $Na_2S_2O_3$ solution to remove larger stains. Note: You should do the removal.

Laboratory Tips *Solubility Tests:* Students should take about 0.1 g of each pure substance for each solubility test. (Show your class how much 0.1 g is and have the students estimate the quantity by eye.) The sample is added to 3 to 5 cm^3 of liquid in a test tube for each test.

Remind students that a consistent volume of liquid is required if comparisons are to be made.

Sublimation Test: Be sure students take very small crystals of each substance, just large enough to see. **Caution:** *Keep the iodine fumes to a minimum! Insure adequate room ventilation.* Note that the can lid must have the outside surface up to avoid substances contacting the lid's inner coating. The use of a candle assures slow, uniform heating.

Identifying the Unknown Mixture: Students are instructed to take a small sample of the mixture for initial testing. Advise students to mix the sample well and to remove only a representative portion for this work. (Have several magnifying glasses available, since some students may request them as an aid to visual identification.)

Separation of Iodine by Sublimation: Gentle, even heating is the key here; very little iodine will escape into the room *if the crystals are heated gradually.* Erratic heating rates will cause sublimated iodine to be deposited on the beaker wall. Gentle heating of the glass will remedy the situation. **Caution:** *Keep the room well ventilated. Remind students to avoid breathing the vapors. Use a fume hood if you have one available.* Students should be prepared to remove H_2O from the evaporating dish by using a medicine dropper.

When properly carried out, this separation method is both interesting and spectacular.

Separation of Sodium Nitrate by Solubility Difference: Discuss some general filtration techniques, such as the folding of filter paper and the transfer of material from a beaker to filter paper. The steam-bath drying takes considerable time; you may elect to have students dry the contents of the evaporating dish overnight in a 110°C oven. Splattering of the contents of the dish can be avoided if the students are careful and if they follow the directions.

Range of Results Preliminary tests:

		Relative Solubility		
		in Cold	*in Hot*	
Solid	*Appearance*	*Water*	*Water*	*in TTE*
I_2	silver gray crystals	I	S	V
$PbCl_2$	white crystals or powder	I	S	I
$NaNO_3$	white crystals	V	V	I
SiO_2	dirty white crystals	I	I	I

The only substance in the experiment that sublimes is iodine.

Sample calculations for two representative unknown mixtures:

a. If unknown is a mixture of $I_2 + SiO_2$:

mass of initial sample: 65.09 g (beaker + sample)
− 61.44 g (empty beaker)
3.65 g sample

mass of SiO_2: 64.57 g (beaker + SiO_2)
− 61.44 g (empty beaker)
3.13 g SiO_2

$$\%SiO_2 = \frac{3.13\text{ g}}{3.65\text{ g}} \times 100 = 85.8\%\ SiO_2$$

$$\%I_2 = 100.0 - 85.8 = 14.2\%\ I_2$$

b. If unknown is a mixture of $PbCl_2 + NaNO_3$:

mass of initial sample: 3.96 g (sample + paper)
− 0.84 g (paper)
3.12 g sample

mass of $NaNO_3$ after drying residue in evaporating dish:

41.63 g (evaporating dish + $NaNO_3$)
− 39.46 g (empty evaporating dish)
2.17 g $NaNO_3$

$$\%NaNO_3 = \frac{2.17\text{ g}}{3.12\text{ g}} \times 10 = 69.6\%\ NaNO_3$$

$$\%PbCl_2 = 100.0 - 69.6 = 30.4\%\ PbCl_2$$

Almost all your students will correctly identify the substances in their two-component mixtures. The calculated percentage compositions may vary by as much as 5 to 10 percent among students, however, because of the stratification of the mixture and nonrepresentative sampling. Analysis of different portions of the unknown mixture may well give slightly different results because the mixtures are nonhomogeneous.

Postlab Discussion Center your postlab discussion on questions relating to the results, sources of error, percentage error (optional), and specific observations that students have made in carrying out this experiment. Study the accumulated data from all students. Discuss.

Consider why ice disappears in winter even if the temperature remains below the melting point of ice. Discuss the physical properties involved in the various separation methods. Also go over properties that are considered in differentiating between mixtures and pure substances. On what basis did students select their methods of separation? Is there any single idea common to all of the decisions that were made?

A-12 PHYSICAL PROPERTIES AND CHANGES

Almost all students readily grasp the notions of physical properties and physical changes. The concept of density may not at first be so readily understood by every student. Take time to introduce this important and characteristic property.

After discussing the photographs on page 20, suggest to your students that they make a list of other materials in their environment that undergo changes in state similar to those exhibited by ice, water, and steam.

Have students calculate the density of each of the materials used in the earlier experiment *A-7 Mass and Volume,* basing their calculations on the class data collected at the time they did the experiment. Suggest to your students that they refer to a chemical handbook to check the accuracy of the calculated densities.

If your students would benefit from a greater exposure to the concept of density, they could carry out the following activity.

Miniexperiment This is a supplementary activity to support section *A-12 Physical Properties and Changes.* Since students have been introduced to the concept of density, they can apply their new knowledge to determine the actual thickness of a piece of aluminum foil, if they know that the density of aluminum is 2.70 g/cm^3. Provide each student with a rectangular piece of either heavy duty or regular aluminum foil. Select pieces that are about 20 cm long. Have students carefully measure the mass, length, and width of their foil samples. These measurements lead to the determination of the thickness of the foil:

mass (m) ______ g
length (l) ______ cm
width (w) ______ cm
area ($l \cdot w$) ______ cm^2
density (d) ______ g/cm^3

Calculation of thickness (t):

$$d = \frac{\text{mass}}{\text{volume}} = \frac{\text{mass}}{\text{area} \cdot \text{thickness}} = \frac{m}{l \cdot w \cdot t}$$

$$t = \frac{m}{l \cdot w \cdot d} = \frac{\text{g}}{\text{cm} \cdot \text{cm} \cdot \text{g/cm}^3} = \underline{\hspace{3cm}}\ \text{cm}$$

The following demonstration can be used to further explore the concept of density.

Demonstration *The U-Tube Puzzle:* This attention-getting display stimulates considerable interest and provides another opportunity to discuss and apply the concept of density.

Before class, make a long U-tube from a full length of 6-mm (or larger) stock glass tubing, spacing the two arms about 4 cm apart. Mix 4 drops of 0.1-percent methylene blue (food coloring can also be used) with 25 cm^3 water in a beaker. In a second beaker, mix 4 drops of 0.1-percent methylene blue with 25 cm^3 methanol. Holding the U-tube at a 45-degree angle, add the water solution with a small pipet until the tube is a little less than half full. Next, add the methanol solution until it is about 6 cm from the top of the U-tube. (Add both solutions to the same U-tube arm.)

Allow the students to "catch you" filling the U-tube at the start of the class period (just adding the last bit of methanol solution). Hold the tube upright; the blue liquid rests at different levels in the two arms. Show that there are no obstructions in the tube by tipping the tube and allowing fluid to flow from one arm to the other. Set up the U-tube as a display and challenge the students to explain their observations. You can leave the U-tube on display for several weeks (or months).

EXPERIMENT
A-13 CHARACTERISTIC PROPERTIES

In doing this experiment, your students will determine several physical properties of a pure liquid and of a liquid mixture. The physical properties determined are density, boiling point, and freezing point.

Concepts

- A pure substance is characterized by well-defined numerical values for its density, freezing point, and boiling point.
- Mixtures are characterized by a range of numerical values for properties such as density and freezing point.

Objectives

- Calculate the density of a pure liquid.
- Determine freezing (melting) point and boiling point of a pure liquid.
- Identify the physical changes associated with the plateaus in graphs of warming and cooling data.
- Identify an unknown substance, given numerical values for physical properties such as density, melting or freezing point, and boiling point, and given a table of values for a number of substances.
- Formulate an explanation for deviations between laboratory results and accepted results.

Estimated Time This activity takes two lab periods, plus prelab and postlab time. A good breaking point is after *Part 3,* the boiling point of a pure substance. *Part 2* and *Part 3* graphs are to be done as homework assignments. Postlab discussion is held the next day.

Student Grouping Pairs

Materials

15 ring stands
15 universal clamps
30 test tubes, 13 mm × 100 mm
boiling chips
ice water
30 400-cm^3 beakers
15 medicine droppers
15 thermometers, $-10°C$ to 110°C
15 10-cm^3 graduated cylinders

You will also need 250 cm^3 of a known solution selected from the list provided in the student module, page 25. Do *not* use acetic acid. (This is listed to serve as a distraction only.) A good choice is *t*-butanol (*tertiary* butyl alcohol or 2-methyl-2-propanol) or cyclohexane.

Advance Preparation Depending on the classroom air temperature, you may wish to warm the *t*-butanol slightly to be sure that it is above its freezing temperature (25.5°C) before starting the experiment. Also, locate a supply of ice.

Prelab Discussion In order to keep the experiment inquiry-oriented, limit your prelab discussion to procedure suggestions.

Laboratory Safety *Stress safety precautions. Some of the liquids are flammable. Instruct your students to keep the liquids away from direct contact with open flames.*

Caution the students to be careful in using thermometers. If thermometers are broken, there is a risk in breathing toxic mercury vapor. If breakage occurs, mercury should be collected and disposed of. Explain how you want this done, if necessary. Also caution students about mercury damage to silver and gold jewelry.

Emphasize to students that they should not inhale any fumes from liquids in the laboratory. The room should be well-ventilated. Protective glasses are mandatory. Long hair should be tied back.

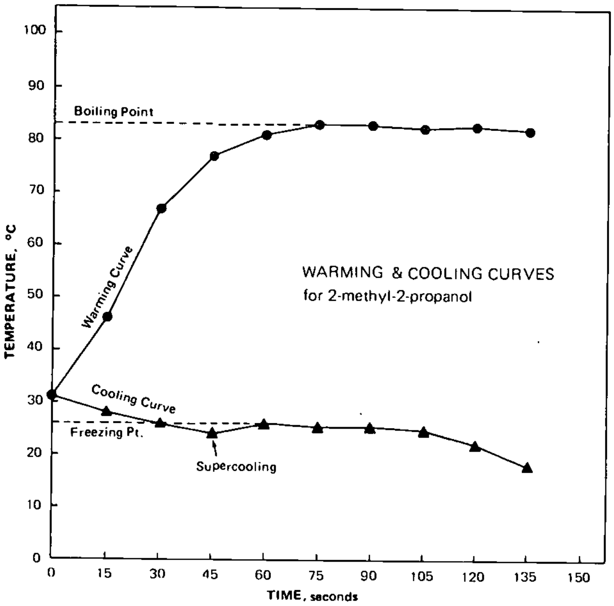
Laboratory Tips Be sure students fully immerse their liquid sample in the ice-water bath when they proceed with *Part 2* and *Part 4.* This is done easily if the test-tube clamp is attached just below the lip of the test tube. Continual thermometer stirring is not essential; when the system freezes, the student should not force the thermometer to move. Students should not lift the thermometer from the test tube during the cooling run.

Repeat the caution about flammable liquids when your students move into *Part 3.* Burner flames must be kept away from the open end of the test tubes. Explain that the function of the boiling chip is to reduce the danger of the liquid "bumping" out of the test tube while boiling. The irregular surface of a boiling chip provides a place for vapor bubbles to form and grow.

Caution: *Students should not add the boiling chip to an already heated liquid, since this may cause the liquid to fizz violently out of the tube.*

When the students proceed with *Part 3,* you may wish to suggest to them that they lift the thermometer bulb out of the boiling liquid to determine the temperature of the vapor rising from the liquid after their time-temperature data are complete. (Call attention in your postlab discussion to the observation that the vapor temperature is the same as the temperature of the boiling liquid.)

Range of Results Representative cooling and warming curves for one possible substance, 2-methyl-2-propanol (*t*-butanol):



Almost all students will find that the prepared mixtures for *Part 4* have lower freezing points than the pure liquids' values in *Part 2.*

Postlab Discussion The discussion can be based on the graphs that students prepare from their laboratory data, as well as on the questions that follow the experiment. Discuss the graphs in detail. Have students compare their characteristic curves for mixture and a pure substance. In this comparison, the students are likely to focus on some of the following observations and possible interpretations.

- **a.** Different students working with the same pure liquid are not likely to produce heating graphs and cooling graphs that are identical. Heating and cooling rates will vary, depending on the amount of sample taken, the degree of stirring, the temperature of the bath, and the size of the bath.
- **b.** Despite differences in the graphs for the same pure substance, the freezing "plateau" and the boiling "plateau" will appear at approximately the same temperature for all the samples of the pure substance.
- **c.** Some graphs may display evidence of supercooling (see sample graph). If it seems appropriate with your group, you can discuss this effect in detail.
- **d.** The cooling curve for the mixture is different from the curve for the pure liquid substance. Some students will report that their mixtures did not freeze at all.
- **e.** Nearly all students will observe that the freezing point of the mixture is lower than that of the pure liquid.

Discuss the significance of the plateaus on the graphs, and associate them with the freezing point and the boiling point for the substance. The early evidence of bubbles during the heating trials probably results from the escaping of dissolved gases; some students may confuse this with the actual boiling of the liquid. To show the difference, cool a freshly boiled water sample and then reheat it. The early evidence of bubbles will be missing.

The antifreeze question introduces a practical application of changes in freezing point. The large freezing point depression permits ethylene glycol to lower the freezing temperature of pure water significantly, thus providing winter freezing protection for a car's cooling system. The boiling point of a mixture of ethylene glycol and water is somewhat higher than that of pure water.

As an extension to this experiment, some students may be interested in investigating the boiling point of a mixture, using the same mixture as in *Part 4.* The effect of a volatile solute on the boiling point of the pure liquid is difficult to predict and to explain—azeotropic mixtures are possible; the boiling point of the mixture may be lower than either pure liquid, for example. However, students can at least confirm a general principle if you elect to carry out this experiment extension: the boiling characteristics of a mixture are different from those of the pure liquid.

You may wish to pose a general question about the warming curve for a pure liquid. When heat energy is added to a cool liquid, the liquid temperature rises. When the liquid boils, however, the liquid temperature remains constant even though more heat is still being added. Where does this heat energy go during the boiling process? What *is* boiling? You needn't seek answers at this point; these concerns lead directly to the next section of the student module, *Matter in Motion.*

A-14 IMPURITIES AND IMPORTANCE

Students may be interested in how a chemist can determine the freezing or melting point of a substance (such as the benzoic acid mentioned in the text) in a more accurate way than the experiment *A-13 Characteristic Properties* suggests. If your school has a melting-point apparatus that tests a sample placed in a sealed capillary tube and circulating oil bath, demonstrate this to the students. More sophisticated melting-point equipment is described in scientific-supply house catalogs.

If students have satisfactorily met earlier lab objectives, you may elect to skip experiment *A-15* with no loss in the module's continuity. On the other hand, some teachers find that this activity has considerable appeal to some students.

EXPERIMENT
A-15 IDENTIFYING A SUBSTANCE

The purpose of this optional experiment is to identify an unknown liquid, basing the identification on techniques and concepts developed earlier in the experiment *A-11 Properties and Separation* and in experiment *A-13 Characteristic Properties*. No new laboratory skills are involved.

Concept

- A combination of physical properties is necessary to identify an unknown liquid.

Objectives

- Collect data on the densities, boiling points, freezing points, and solubilities of substances.
- Identify an unknown liquid from such data.

Estimated Time One Period

Student Grouping Pairs

Materials See materials list for *A-11* and *A-13*. Use three or four different unknowns, 10 cm^3 per sample. The total volume of unknowns needed is 200 to 400 cm^3, depending on whether the experiment is performed by individuals or lab pairs.

It is not necessary for each unknown to have both boiling point and freezing point within the 0 to 100°C range. As long as at least one of these two values is measurable with the described procedure, students can identify the substance reliably, using solubility and density measurements to narrow the field. **Caution:** *Do not give acetic acid as an unknown.*

Advance Preparation Decide on the unknowns to be used. Give each student a 10-cm^3 sample for analysis.

Prelab Discussion Very brief! This amounts to a "graduation exercise" for students in using characteristic properties to identify substances. Review the safety hazards associated with *A-11* and *A-13*. Remind students to use a boiling chip when determining the boiling point of a substance.

Laboratory Tips Refer to the *Laboratory Tips* suggested for carrying out *A-11* and *A-13*.

Range of Results Almost all students will successfully identify their unknown. The satisfaction of meeting this challenge will build laboratory confidence in many students.

Postlab Discussion Identify the unknowns. Discuss any problems that students experienced in conducting the analysis.

ANSWERS TO QUESTIONS

(Student module page 25)

1. (a) mixture; (b) pure substance; (c) mixture; (d) mixture; (e) pure substance; (f) pure substance
2. 1.9 kg alcohol
3. (a), (c), (d), and (e) are physical changes.
4. The graph sketch should show declining water temperature until all the ice has melted, or until an ice-water mixture is obtained at 0°C. If such an equilibrium state is present, the temperature will plateau at 0°C. Such an equilibrium plateau would occur at a temperature lower than 0°C for the

sugar-water system. (Some students may like to try the experiment.)

5. A range of answers is likely here, suggesting the fact that terms like *pure* are often used in a relative sense.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Which of the following is an example of a mixture?

   A. Sugar B. Diamond C. Beach sand D. Salt

2. Which of the following is an example of a solid that sublimes?

   A. $PbCl_2$ C. NaCl
   B. Cu D. I_2

3. A mixture of Fe and SiO_2 contains 45 g Fe in a 150-g mixture. Calculate the mass percent of Fe in the mixture.

$$\% \text{ Fe} = \frac{45 \text{ g}}{150 \text{ g}} \times 100 = 30\% \text{ Fe}$$

4. Which of the following is an example of a solid that is very soluble in cold H_2O?

   A. Zn C. CuO
   B. $NaNO_3$ D. I_2

5. After a magnet was used to remove the iron from a 3.90-g sample of iron and sulfur, the mass of sulfur remaining was 1.20 g. The percentage of iron in the mixture is:

$$\% \text{ Fe} = \frac{3.90 \text{ g} - 1.20 \text{ g}}{3.90 \text{ g}} \times 100 = 69.2\%$$

   A. 69.2 C. 30.8
   B. 44.5 D. 16.8

6. You are assigned to measure the density of a liquid. Your lab partner gives you the following data:

   Mass of 10-cm^3 graduate (filled with liquid) = 18.73 g
   Mass of 10-cm^3 graduate (empty) = 10.23 g

   What is the density of the liquid?

   A. 1.83 cm^3/g C. 0.85 g/cm^3
   B. 1.18 cm^3/g D. 0.55 g/cm^3

7. A student was asked to identify an unknown compound by determining its density, boiling point, and melting point, and then referring to the following table:

   The student's findings: Density = 0.85 g/cm^3
   Boiling point = 79°C
   Melting point = 4° C

Compound	*Melting Point (°C)*	*Boiling Point (°C)*	*Density (g/cm^3)*
acetone	−95	56	0.8
allyl chloride	−136	45	0.9
benzene	+5	80	0.9
n-butyl chloride	−89	118	0.8
ethyl alcohol	−117	78	0.8

By referring to the table, the student found the unknown to be:

   A. Allyl chloride C. Ethyl alcohol
   B. Benzene D. Acetone

Matter in Motion

This section of the module surveys the three states of matter. Here we introduce the kinetic molecular theory as a way of explaining the behavior of matter in solid, liquid, and gaseous states. Scientific models—their construction, testing, and use—are highlighted. This is the beginning of a particulate, microscopic view of matter, as contrasted to the macroscopic properties and behavior of matter studied so far.

A-16 FROM MODELS TO THEORIES;
A-17 FROM ORDER TO DISORDER;
A-18 TOWARD GREATER DISORDER

The three sections *A-16* to *A-18* tie together as a single, coherent explanation of the kinetic molecular theory (KMT). The kinetic molecular theory, as your students will learn, explains the states of matter and accounts for the observed changes in state. Temperature rises (figuratively) through these three sections as we follow a solid sample of material through melting, warming in the liquid state, boiling, and finally into the gaseous state.

We intend this particular KMT narrative to serve as an example of a general activity of scientists, one which involves mental activity rather than physical effort at the lab bench. Chemists propose an *interpretation* for the observations they make. The interpretation is a theory, or a mental model (we do not make any distinction between these terms), which it is hoped, will account for the specific observations that are noted. Theories and models are never said to be true in an absolute sense. They simply represent human ideas about why things behave the way that they do. Theories are always subject to change. All we ask is that the theory or model account for existing observations, and that it suggest valid predictions for future observations. Thus we speak of a theory or model as being useful or fruitful.

Here are three demonstrations you may wish to use in a discussion of the kinetic molecular theory:

Demonstration *A Simple KMT Device:* A homemade KMT apparatus for overhead projection provides an inexpensive and useful demonstration of molecular motion. To make the device, you will need some tape, glass beads, two petri dish tops or bottoms, and an electric toothbrush. You will also need an overhead projector. Vibrating beads will show up on the projector screen as "moving molecules."

Fill the top or bottom of a petri dish half full of a single layer of small glass beads, each approximately 3 mm in diameter. Invert a second petri dish of the same size over the dish that contains the beads. Tape the two adjoining dish edges together with masking tape. Hold the bead-filled petri dishes just above the projector stage in one hand.

To put the "molecules" in motion, touch the edge of the petri dishes with a vibrating electric toothbrush. The vibrating bristles will cause the beads to move, projecting a movement on the screen that represents molecular motion. You can regulate the relative degree of order and motion among molecules by tipping the dish and by varying the intensity of vibration. With practice and some patience, it is possible to simulate the melting of a crystalline solid and the evaporation of a liquid to form a gas. The resulting image on the screen gives students a fairly useful model of changes in molecular motion as temperature increases. It also illustrates phase change.

Demonstration *The Collapsing Can:* Boil a small amount of water in an uncapped metal can. (A spirit duplicator fluid can works fine. Empty it and rinse it well, however!) Keep boiling the water until the container is full of water vapor. Then remove the heat and quickly replace the cap. Without comment, set the can aside, in full view of the students. Go on with your regular discussion. The can will eventually collapse rather spectacularly. Ask for explanations. Relate results to pressure and molecular motion.

Some students may have seen the collapsing-can demonstration in an earlier science class. If so, call their attention to an observation that is often overlooked —a faint fizzing or sizzling sound can be heard from within the collapsed can. Challenge your students to offer an explanation for this noise. Some may correctly suggest that the remaining water in the can is boiling; a close look at the phenomenon is contained in the next demonstration. To show how the walls of the can are pushed out, reheat the sealed, collapsed can. **Caution:** *Heat slowly and with caution; do not allow high pressure to build up in the can. Avoid an explosion!*

Demonstration *Boiling Cool Water:* Place a thermometer in a 250-cm^3 beaker half full of 30–35°C water. Place this assembly in a bell jar, and then evacuate the bell jar with a vacuum pump. The water will begin to boil. In time, students will note the change in temperature that occurs during boiling (the temperature will noticeably drop). This demonstration leads to a discussion of the energy associated with this change of state. (You can increase the boiling effect by carefully placing a small beaker of concentrated sulfuric acid in the bell jar. The acid absorbs water vapor, lowering the total pressure above the water.)

The kinetic molecular theory can be extended to explain the concept of vapor pressure. Review the conditions necessary for a liquid to boil. (A liquid begins to boil when its vapor pressure equals the air pressure above the liquid.) Check your students' understanding of the kinetic molecular theory and of the energy associated with a change in state. Bear in mind, however, that this introductory module serves only as a stage-setter for later modules. Do not try to teach KMT in an exhaustive manner. Keep things moving!

You will notice that the quantitative gas laws are not introduced in this module. They are not needed to support any IAC module except *Communities of Molecules: A Physical Chemistry Module;* they are introduced there to the extent needed. A descriptive introduction to KMT and molecular motion as influenced by temperature and/or pressure changes is more useful to students in understanding general atmospheric effects, for example, in environmental topics.

Miniexperiment Fill a large beaker with hot tap water. Fill a second beaker with cold tap water. Wait a minute or two, and then add one drop of food coloring to each beaker at the same time. Do not touch or stir the water. Observe what happens for several minutes. How do you explain the difference in the behavior of the food coloring in the hot and the cold water? What features of the kinetic molecular theory are suggested?

Miniexperiment Punch a small, pin-size hole in the bottom of an empty large juice can. Remove the top of the can; rinse the can thoroughly. Make a mark with masking tape about halfway up the side of a 100-cm^3 graduated cylinder. Support the juice can above the cylinder so that liquid passing through the hole will drop into the graduated cylinder.

Chill 1000 cm^3 of water with ice cubes. Remove the ice cubes. Pour the cold water into the juice can, marking the initial level of the water in the can and noting the starting time. Let the water run through the hole in the can into the cylinder. How long does it take to fill the cylinder to the masking-tape mark? Pour out the remaining cold water from the can.

Repeat the miniexperiment with hot tap water. Be sure to fill the juice can to the same initial mark. (Why is this important?) Let the hot water run through the can hole into the cylinder. How long does it take to fill the cylinder with hot water to the masking-tape level? Compare the two filling times. Explain your results. How could this device be used to "measure" the temperature of a water sample?

MINIEXPERIMENT
A-19 PATTERNS TO MODELS

Some of the fascination and frustration of theorizing and model building can be conveyed to students by simple "find-the-pattern" exercises similar to the one shown here. In fact, once the idea is made clear, you'll find students eager to suggest extensions of this activity themselves. You may wish to set some time aside each week or two for similar challenges—some of the spirit of "doing science" can be communicated nicely in this manner.

Here are the solutions to the patterns posed in the module.

I. This represents, of course, the series of perfect squares. Most students will find this a relatively simple initiation to the miniexperiment. The new terms in the series would be 36, 49, and 64.

II. Perhaps a bit more subtle! Although other patterns can be discerned here, the simplest pattern is that the series includes all straight-line capital letters; letters written with curves (B, C, D, G, etc.) are omitted. Thus the next terms would be N, T, and V, with the series terminated by W, X, Y, and Z.

III. This series has a capricious look to it; the pattern seems to defy analysis. Some students have left class muttering in frustration at this one. The series is composed of descending perfect squares written backwards—which is more easily illustrated than described.

First, the perfect squares backwards, starting with 9^2: 81, 64, 49, 36, 25, etc. Now reverse the digits on each to produce the pattern shown in the module: 18, 46, 94, 63, 52, etc. Thus the next terms in the series would be 61 (16 backwards), 9, and 4, if the pattern holds.

IV. This series represents the ultimate challenge to many individuals, yet it is based on one of the simplest series that can be imagined. The letters may even have a vaguely familiar "ring" to them. It's a series students already know in a slightly different form, in fact. To distribute the fascination and frustration evenly among *all* individuals, we have decided *not* to present a description or explanation of this series, so that you can join with the students in tackling this challenge. (One clue: the apparent pattern of double letters does *not* continue through the next few letters, based on the regularity we have discerned in the series ourselves.) When you discover the pattern, you will have absolutely no doubt that you are correct, which is reward in itself. Enjoy!

ANSWERS TO QUESTIONS

(Student module page 31)

1. Accept a range of answers, and clarify the suggested "model" people through class discussion.
2. The liquid with the larger particles would probably have the higher boiling point—a higher level of thermal energy would be needed to cause this phase change.

3. The kinetic energy is transformed into heat energy, sound energy, changes in potential energy in the wall and in the car!
4. The increased motions of iron atoms at one end gradually cause nearby atoms to also move more vigorously, thus allowing a gradual "heating up" of the entire rod.
5. The 25 km/h bicyclist will possess greater kinetic energy, assuming that the two bicycles are of equal mass, and that the bicyclists are also of equal mass.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Which state of matter represents (a) the most ordered arrangement of particles, and (b) the most disordered, random arrangement of particles?

   (a) solid, (b) gas

2. If no attractive forces existed between particles, what state of matter would be most commonly found among substances? Explain your answer.

   The gaseous state would prevail, since this state represents the behavior of "detached," independently moving particles.

3. Which one of the following does *not* represent a test of a useful scientific model or theory?

   A. Does the model *describe* the facts that we need to describe?

   B. Does the model have features that can be *proven* to be *true* reflections of reality?

   C. Does the model *predict* new phenomena that we can then observe?

   D. Does the model *contradict* other laws or facts that we accept?

Chemical Changes

This portion of the module provides a laboratory-oriented introduction to a variety of chemical changes and to some of the fundamental laws associated with reactions. Word equations and symbolic equations are introduced here to represent reactions. (Actual student practice in writing and balancing equations will follow later in this module and should not be stressed here.) Laboratory data gathered in experiment *A-23 Relative Masses of Atoms* will be used later in the *Structure of Atoms* section.

A-20 IT'S ELEMENTAL!

We state that 106 elements have been currently identified. The names for elements 104, 105, and 106 are not yet established officially because U.S. and Soviet scientists have rival claims for synthesizing these elements. The Americans have suggested the names rutherfordium (104) and hahnium (105). The Soviet choices are kurchatovium (104) and nielsbohrium (105). It's doubtful that this dispute will be settled for many years, in view of the fact that the evidence for these short-lived elements is extremely difficult to interpret and to reproduce.

Some students may be interested in doing outside reading on the history of alchemy or on the modern synthesis of new elements. Invite these students to submit brief reports to the class on their findings. Nuclear reactions are discussed in detail in *The Heart of Matter: A Nuclear Chemistry Module*. Another research idea might be the history of the balance, starting from the time of the Egyptians until the present-day electronic balances.

The brief discussion on synthesis and analysis at the end of section *A-20* leads directly to miniexperiment *A-21 Synthesis of a Compound.*

MINIEXPERIMENT
A-21 SYNTHESIS OF A COMPOUND

The purpose of this miniexperiment is to provide evidence leading to the recognition of chemical change.

Concepts

- A chemical change is associated with changes in the observed properties of the materials.
- In some chemical reactions, energy must be added to initiate the chemical change.

Objective

- Recognize evidence for chemical change.

Estimated Time One-half to one period

Student Grouping Pairs

Materials

20 g copper (Cu) turnings
10 g sulfur (S), flowers (powder)
15 18 × 150-mm test tubes (hard glass)
15 test-tube clamps
15 Bunsen burners
15 stirring rods

Prelab Discussion Keep your prelab comments to a minimum; let the students discover the reaction for themselves. Assemble a laboratory setup before your laboratory session and have it on display. Be sure that students use no more than 0.5 g of sulfur. If a greater amount is used, the sulfur dioxide fumes will raise the anxiety level of other teachers in the building.

Laboratory Tips It is important that copper be in excess in the mixture, allowing all available sulfur to react and form the sulfide. The amounts specified in the procedure will ensure this. Try the reaction yourself to preview the proper techniques prior to class.

Heating the test tube gently at first allows the sulfur to melt thoroughly. This helps ensure complete reaction with the excess copper when more vigorous heating is started. Final heating should be vigorous. The room should be well-ventilated.

Experience suggests that the contents of a well-heated test tube are relatively easily removed with the aid of a stirring rod, leaving a relatively clean tube. Have a waste container handy. Save the discolored tubes for use in this experiment next time you teach this module.

Range of Results Students will observe that the dark "cinder" formed in the reaction is not malleable or shiny, in contrast with the copper present initially. Some students may observe that the formation of the compound liberates large quantities of heat, once the reaction begins. The humming noise observed by some students during the reaction will be a source of considerable interest, as well.

Postlab Discussion Have students compare their observations. Ask them how they know that a chemical change occurred. See if any students can write a balanced equation for the reaction, if you identify the product formed as copper(II) sulfide, CuS. Develop a second equation expressing the burning of sulfur in air to form sulfur dioxide. You might like to mention that sulfur-containing coal samples also burn to produce sulfur dioxide (SO_2), a source of air pollution:

$$Cu(s) + S(s) \rightarrow CuS(s)$$

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

Mention that "burning in air" generally refers to the chemical combination of a substance with oxygen (O_2). Use this postlab discussion to lead into experiment *A-22 Chemical Reactions*. As they do this experiment, your students will carry out and observe a wide range of reactions, starting with metallic copper similar to that used here.

EXPERIMENT
A-22 CHEMICAL REACTIONS

This experiment enables students to observe a variety of chemical changes. Metallic copper is taken through a series of chemical reactions that eventually lead to the recovery of the copper metal. The experiment reaffirms certain fundamental laws, such as the constant composition of matter and conservation of mass, and illustrates the idea of recycling.

Concepts

- Mass is conserved in a chemical reaction.
- Chemical reactions can be usefully classified by type (i.e., synthesis, precipitation, acid-base, oxidation-reduction).
- Chemical reactions can be represented symbolically by equations.
- The pH value of a solution expresses its relative acidity.
- Compounds have definite compositions.
- Recycling often allows the recovery of a material initially "consumed" in a chemical reaction.

Objectives

- Demonstrate the following laboratory skills: safe handling of potentially hazardous materials, decanting, and removal of moisture from a precipitate.
- Classify a solution as either neutral, acidic, or basic, given the solution and pH or litmus paper.
- Write word equations and symbolic equations illustrating a chemical change.
- Illustrate, with suitable word equations, the steps involved in the recycling of a substance.

Estimated Time Three-to-four-day period

Day 1: Brief prelab discussion. Weigh copper sample, add HNO_3, let metal dissolve. (Half-period)
Day 2: Continue procedure through beginning of Conversion 5, allowing aluminum metal to react with acidic $CuCl_2$ overnight. (Full period)
Day 3: Finish procedure, air-drying recovered copper overnight. (Full period)
Day 4: Weigh dried copper, calculate percent recovery. Postlab discussion. (Full period)

Note: If copper metal turnings are used to start, it may be possible to combine *Day 1* and *Day 2* into one laboratory session. These turnings will fully dissolve in HNO_3 within five minutes, permitting subsequent steps to be performed immediately. Such a session may be too "full" for some of your students, however. Use your judgment.

Student Grouping Pairs

Materials

300 cm^3 6 M nitric acid (HNO_3)
300 cm^3 6 M sodium hydroxide (NaOH)
800 cm^3 6 M hydrochloric acid (HCl)
25 g copper (Cu) turnings or wire
25 g aluminum (Al) wire, 18-gauge or heavier
500 cm^3 acetone (optional)
ice
15 400-cm^3 beakers
15 600-cm^3 beakers
15 50-cm^3 graduated cylinders
15 evaporating dishes
15 vials litmus paper or pH paper
15 watch glasses, 90 mm diameter
15 stirring rods

Advance Preparation To prepare solutions, add each solute to enough distilled water to give you the required amount of each solution:

500 cm^3 6 M HNO_3: 115 cm^3 conc. HNO_3 per 500 cm^3 solution
500 cm^3 6 M NaOH: 120 g NaOH per 500 cm^3 solution
1000 cm^3 6 M HCl: 500 cm^3 conc. HCl per 1000 cm^3 solution

Caution: *In making up these solutions, be sure to add the concentrated acid to water, not the other way around!* (See *Laboratory Safety*)

A neighborhood hardware store may be an inexpensive source for the uncoated aluminum wire.

Prelab Discussion Since the experiment takes several days, there is no need to discuss all details of the procedure at the start. Plan on demonstrating and discussing these laboratory techniques as appropriate:

1. pouring acids and bases from lab bench bottles
2. using the fume hood
3. decanting and washing a precipitate
4. transferring liquids and solid material from one container to another
5. emergency action to be taken if chemicals spill on skin

Laboratory Safety Give careful attention to proper laboratory manipulations and safety precautions, but do not discuss the actual reactions to be observed except in general terms. Permit the students to enjoy the experience of observing these chemical changes for themselves. Suggest to the students that they keep a record of their observations during the experiment. As time allows, you can discuss items of interest during the next few days.

Corrosive acids and bases are used in this experiment. Be sure that every student wears protective glasses and laboratory apron. Read the detailed comments in the *Laboratory Tips* section that follows. Incorporate in your prelab discussion any of the details that you judge appropriate.

Laboratory Tips *Conversion 1—Changing Cu to $Cu(NO_3)_2$:* A 1.5-g sample of 16-gauge copper wire takes more than an hour to dissolve in 6 M nitric acid at room temperature. By contrast, fine copper turnings will dissolve within 5–10 minutes. If wire is used, the students can simply leave the copper metal sample in the nitric acid over night, stored in the fume hood with a watch glass to cover the beaker. This will reduce the first-day lab activity, so plan accordingly.

Note that word equations and symbolic equations for all reactions in the experiment are included in the student module. The students' responsibility is simply to look at these expressions and relate them to the observations they are making. If you wish, you can introduce formula writing and equation balancing as time permits during these laboratory days. (Sections *A-29 What's in a Name?* through *A-31 The Balancing Act* will cover these skills in more detail later.)

Conversion 2—Changing $Cu(NO_3)_2$ *to* $Cu(OH)_2$*:* The following method is suggested for making the pH or litmus paper tests: A rinsed stirring rod is dipped into the solution and then touched to a piece of the test paper placed on a paper towel on the bench.

For pH paper the "dot" of color formed is then compared with the color scale on the tube. This comparison should be made within thirty seconds after the pH paper is moistened. Discourage your students from dipping or dropping the test paper into the beaker of solution.

The 20 cm^3 sodium hydroxide (NaOH) solution must be added *slowly* to the solution of nitric acid and copper. Considerable heat is liberated in this neutralization reaction. The student keeps this under control by cooling the beaker in an ice-water bath (preferred) or a cold tap-water bath. Instruct your students to keep their faces away from the beaker when the sodium hydroxide is added. In doing so, they will avoid any corrosive mist that might be generated by the reaction.

The pale blue copper(II) hydroxide $Cu(OH)_2$ precipitate that forms might begin to turn brown if excessive heat is generated. (You'll note that the next step involves producing brown-black copper(II) oxide by heating the copper(II) hydroxide. Any copper(II) oxide formed now is premature but totally acceptable.)

Students can move immediately to *Conversion 3* during this second-day procedure.

Conversion 3—Changing $Cu(OH)_2$ *to CuO:* The conversion to brownish-black copper(II) oxide (CuO) is usually completed by the time the system has reached a gentle boil. (Within three to five minutes, with stirring). The copper(II) oxide precipitate formed is considerably more granular and dense than the gelatinous copper(II) hydroxide seen in the last step. To minimize bumping, the heated liquid should be stirred often. Leave the stirring rod in the beaker. When the liquid begins to boil, turn down the burner flame to avoid bumping and localized overheating.

Remove the stirring rod before the beaker and solution are set aside to cool. (Removing it later will stir up the settled copper(II) oxide before decanting.) Five minutes of settling time is sufficient. Demonstrate to your students how the clear liquid can be decanted by holding a stirring rod at the lip of the beaker, allowing the liquid to flow down the rod while the beaker is tipped gently and slowly. About 60–70 cm^3 of material will be left in the beaker after each decanting step.

This decanting, followed by a single rinse with water, is intended to remove most of the excess sodium hydroxide and remaining nitrate ions. At the same time, decanting reduces the total volume of liquid in the beaker.

Proceed with Conversion 4.

Conversion 4—Changing CuO to $CuCl_2$*:* The copper(II) oxide will dissolve in the hydrochloric acid in about one minute, with stirring. The change from muddy brown-black solid particles to a clear blue solution is rather dramatic. This quick reaction sets the stage for the start of *Conversion 5*.

Conversion 5—Changing $CuCl_2$ *to Cu:* If you wish to consider alternative forms of aluminum for this final step, you should recognize that the optimum choice is aluminum wire (uncoated) of sufficient thickness to maintain its strength as a multistranded "handle" that can be withdrawn at the end of the reaction, yet thin enough to present sufficient surface area to allow a reasonable reaction rate. This experiment was tested successfully with the use of 18-gauge aluminum wire, which we consider to be the thinnest-gauge wire that will serve satisfactorily—slightly thicker wire is acceptable. Difficulties with aluminum foil seem to outweigh its convenient availability: the large surface area of the foil creates a rather vigorous reaction that may "boil" out of control. The reaction product includes small aluminum foil fragments that are difficult to remove, as well. Bench-testing of alternative forms of aluminum that are conveniently available to you is encouraged, if the preceding concerns are recognized in advance.

A reliable visual method for estimating the extent of Cu recovery in *Conversion 5* is to note the color of the solution following the aluminum wire reaction—an absence of blue color suggests that virtually all copper has been reduced to metallic state.

Oven drying or steam-bath drying of the recovered copper metal is *not* recommended, because of the possibility that some of the copper will be re-oxidized under such elevated-temperature conditions. The acetone wash hastens thorough air drying of the copper at room temperature. **Caution:** *Observe caution concerning the flammability hazards of acetone. All burners must be extinguished prior to its use.*

Range of Results You can expect considerable variation among students on the percent recovery of copper. Almost all students intuitively expect the recovery to be 100 percent. The students will be interested in discussing possible reasons for lower percent recoveries, and for the few recoveries that seem to be more than 100 percent. Students can contribute thoughts on many possible sources of error. For example, recoveries that calculate to more than 100 percent might be caused by incomplete drying of the copper product, the presence of unreacted aluminum metal in the copper product, the conversion of portions of the copper back to copper(II) oxide in the drying procedure, or a weighing error in the original copper sample used at the start of the experiment.

Identify a mean and median percent recovery value for your class from the grouped student data. The percent recovery for the experimental procedure as written is commonly found to be from 70 percent to 90 percent. Assure your students that results in this range are reasonable and satisfactory. See if they can identify sources of error such as portions of copper or copper-containing substances lost in the decanting and washing steps; the aluminum metal may not reduce all of the copper present in the copper sulfate solution, particularly if incomplete washing and decanting earlier in the experiment allow excess nitric acid to remain in the system.

Postlab Discussion The postlab discussion can be completed in parts, since there are days during experiment *A-22 Chemical Reactions* when full time is not needed for laboratory activity. Use discussion opportunities to associate names with chemical formulas for the simple substances used in this experiment. This is not the time to drill on writing and balancing equations, but this introduction to equations does set the stage for the development of such skills later in the module.

Following this discussion is a flowchart summarizing the steps and reactions of this experiment; it can serve as the focus of your postlab work. Duplicate it in any way you wish and provide a copy for each of your students.

Among the types of reactions represented in this experiment are precipitation, oxidation-reduction, and acid-base reactions (neutralization). This provides a good opportunity to generalize about the types of chemical reactions commonly observed in laboratory work. You can extract some operational definitions for acids and bases from this experiment. (The student can observe the action of acids on metals, the effect of acids and bases on pH or litmus paper, and the neutralization of an acid with a base, with the associated liberation of heat energy.)

Devote some attention to the recovery of the copper in this experiment. You can relate the recovery of copper to the economic and social importance of recycling of materials. Recycle systems of this type seldom result in the recovery of all the original material. In addition, the recovery is often made possible only through the apparent consumption of other materials, such as the aluminum metal in this experiment.

Finally, the experiment provides an excellent review of the kinds of evidence which indicate that chemical changes have occurred:

Evolution of gas.
Formation of precipitate.
Pronounced "heat" effect.
Color change in solution.
Change in odor.

EXPERIMENT A-23 RELATIVE MASSES OF ATOMS

In this experiment students will determine the relative masses of two component elements in a binary compound. Assuming a formula for the compound, the data lead to the relative masses of the atoms involved.

Concept

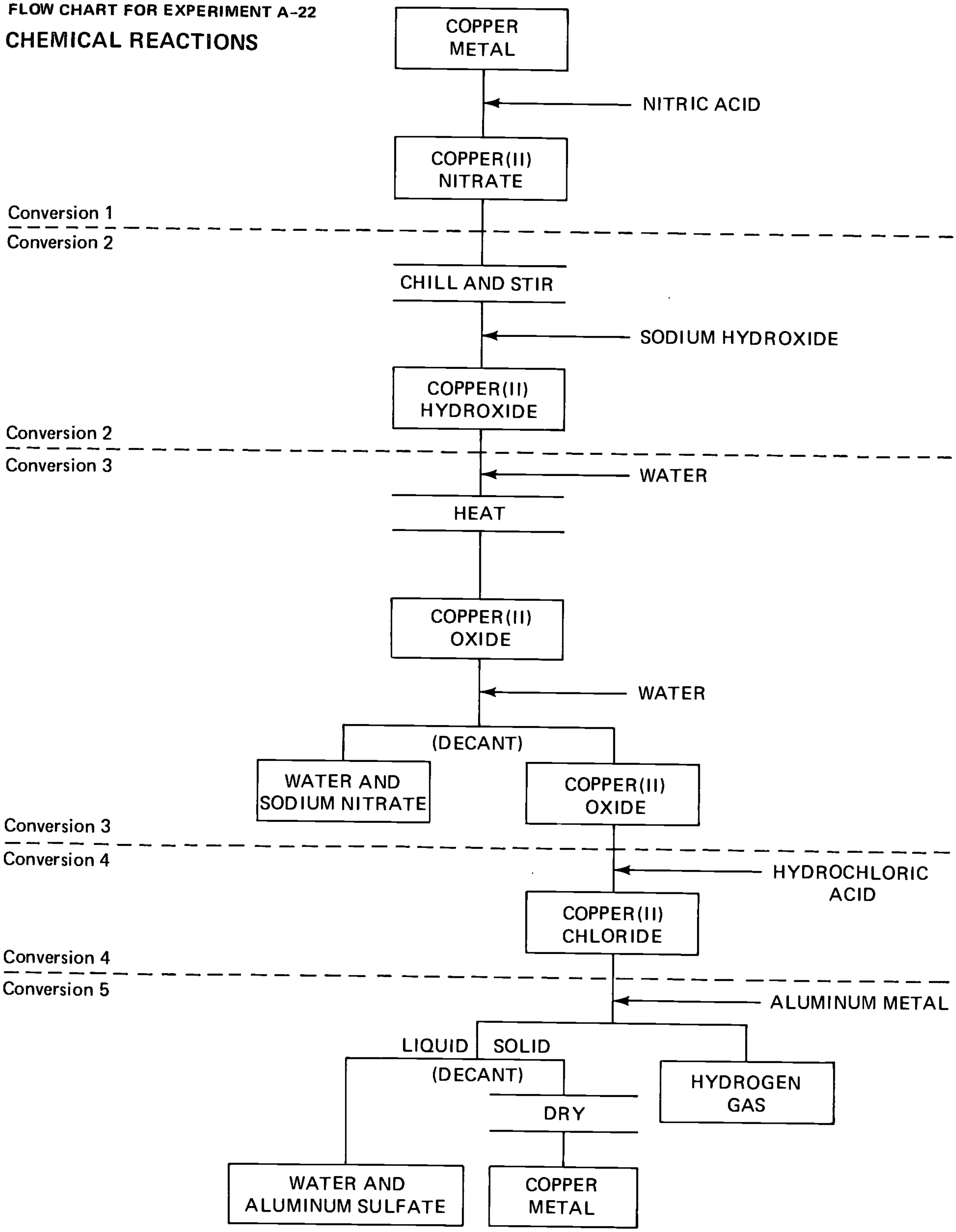
- Elements combine to form compounds in definite mass ratios.

Objective

- Determine the relative masses of the elements in a compound, given data similar to that collected in this experiment.

FLOW CHART FOR EXPERIMENT A-22

CHEMICAL REACTIONS



Estimated Time One period

Student Grouping Pairs

Materials

60 g copper(II) oxide (CuO), powder
15 18 × 150-mm test tubes
15 pieces bent glass tubing
30 universal clamps
supply of burner gas (assumed to be methane, CH_4)
15 0.5–1-m rubber tubing lengths to fit glass tubing

Advance preparation Cut, bend, and fire polish the pieces of glass tubing needed to direct the burner gas into the test tube. Judge the rough dimensions from the illustration of the setup in the procedure. Be sure your 18 × 150-mm test tubes are made of borosilicate glass (Kimax and Pyrex are two trade names).

Prelab Discussion Outline the purpose of the experiment. Point out that this procedure represents a second way to convert CuO to Cu; you may wish to contrast this method with the steps followed in the last part of experiment *A-22 Chemical Reactions*.

Laboratory Safety Review appropriate safety hints with your students. As you proceed with your students, note the cautions in the student module. Careful reading of those cautions and use of common sense will provide your students with a safe laboratory experience.

Laboratory Tips Be sure the clamps used to support the test tubes are not plastic-coated; the plastic will melt and stick to the test tubes, altering their mass. Be sure you bench-test this procedure yourself before supervising the student work in this experiment, since a certain amount of technique is involved.

Consider the test tubes to be expendable, since some copper does fuse to the glass wall; use them for this same experiment next time you teach this module.

If the flow rate of the burner gas through the test tube is too high, the copper(II) oxide cannot be heated sufficiently to complete the reduction. The reason why gas is allowed to continue to flow through the test tube and to burn at the tube mouth for about five minutes after the Bunsen burner is removed is to maintain a reducing atmosphere over the metallic copper while it cools. This prevents oxidation back to CuO. Gas in some regions may be supplemented with substances that interfere with the CuO reduction, but you can use bottled propane gas successfully as a substitute in this experiment.

This burner-gas reduction procedure was presented as an optional teacher's demonstration in the last edition of this module. Many teachers elected to use this as a student experiment, with excellent success, and many have suggested that we include it as part of the student module.

Range of Results The expected mass ratio for Cu/O is around 4.0. Student results may vary from about 3 to 5. You will need to extract a "best" value for the ratio from the collected student results.

One source of variation in the calculated ratios is inherent in the nature of the calculation itself. A small error in the mass of copper recovered introduces a similar error in the calculated mass of oxygen. For example, if the copper mass is low by 0.05 g, then the calculated mass of oxygen (mass CuO – mass Cu) will be *high* by 0.05 g. In this example, the two effects would work together to make the calculated ratio significantly smaller than expected.

Postlab Discussion This is the first completely quantitative chemical investigation the students have completed in this course. It would be appropriate, therefore, to conduct a discussion of the possible reasons why different lab pairs reported slightly different mass ratios. What sources of error can be identified?

The Cu/O mass ratio value will be referred to in a subsequent section of the module, section *A-25 Dalton's Intuitive Leap*. Here the ratio supports the development of an atomic mass scale.

A-24 THE SAME THE WORLD OVER

The chart on page 42 of the student module presents data similar to those collected by students in doing experiment *A-23 Relative Masses of Atoms*. You may wish to point out that the first two columns summarize laboratory data, while the third column (Mass S) is simply the calculated difference between column 2 and column 1.

The law of definite proportions, which ends this *Chemical Changes* section of the module, provides an important observation about compounds that led John Dalton to propose his atomic theory. (This is the theme of the next part of this module.) From our "atomic" perspective today, it is difficult to understand the importance that early chemists attached to the law of definite proportions, but from such observations the modern atomic theory grew.

Note: The bracketed formulas contained in the quotation from Prout are not part of his original statement, but are added to identify the substances named by him.

Ask your students to list and find pictures illustrating other events that happen in their everyday life that can be classified as chemical changes. Use the photograph on page 43 illustrating the burning of a match as a takeoff point for this activity. Discuss and display student findings.

ANSWERS TO QUESTIONS

(Student module page 43)

1. (7.64 g Hg)/(0.61 g O) = 12.5 (or 13, to 2 significant figures)
2. temperature change; formation of a precipitate; formation of a gas; color change; disappearance of a reactant
3. See student module, pages 34–35.
4. (a) zinc; (b) iron; (c) manganese; (d) magnesium; (e) aluminum; (f) sulfur; (g) nitrogen; (h) mercury
5. Typical answers (others are aiso possible): (a) $Cu(OH)_2$, copper(II) hydroxide; (b) NO_2, nitrogen dioxide; (c) Cu, copper; Al, aluminum; (d) $Cu(NO_3)_2$, copper(II) nitrate; $Cu(OH)_2$, copper(II) hydroxide; CuO, copper(II) oxide; $CuCl_2$, copper(II) chloride.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. A student weighs a 2.65 g sample of FeO and places it in a test tube with charcoal. After heating and allowing the newly formed Fe to cool, the amount of Fe found was 2.07 g. This mass ratio of Fe/O in FeO is:

   A. 2.8 B. 3.6 C. 2.2 D. 1.3

2. If the combining mass ratio of element X to element Y is 3:1 and the combining ratio of Y to Z is 1:3, then the combining ratio of X to Z is:

   A. 9:1 B. 1:1 C. 1:3 D. 1:9

The Structure of Atoms

This portion of the module has no experiments, although the material is based on laboratory work done in previous sections. It is desirable to keep your development of atomic structure from becoming too lecture-oriented. There is ample opportunity for students to carry out exercises and activities such as determining atomic masses, writing isotopic notation, and devising models to explain experimental facts. Keep this section student-centered by getting students heavily involved in discussion.

A-25 DALTON'S INTUITIVE LEAP

We introduced the idea of using a model to explain observations in section *A-16 From Models to Theories*. At that point, you will recall, the students were encountering the kinetic molecular theory. The same approach is used here to show how Dalton developed his atomic theory. The notion of an "intuitive leap" might require some elaboration in class.

Some students may need help with the ratio calculations given on pages 46–47 in their text. These are most easily understood in terms of simple proportion.

Our current atomic mass scale is based on the carbon-12 isotope, which, as you know, is given a mass of *exactly* 12.0000 unified atomic mass units (u, formerly symbolized amu). But on page 47 we have found it convenient to speak directly of the atomic mass of oxygen as 16.0 u. Although the actual atomic mass of oxygen is given as 15.9994 on many periodic tables, that figure rounds off to 16.0 u to three significant digits. This degree of precision is adequate for our use. It is unnecessary to discuss the carbon-12 standard at this time.

Miniexperiment A possible activity for interested students would be for them to use an original mass standard in constructing a table of atomic masses. Suggest that they compile an atomic mass table that would be based on the mass of oxygen being defined as 20, or hydrogen taken as 10.

A-26 INSIDE THE ATOM

Notions of the electron, proton, and neutron should be familiar to most students in your class. In earlier courses, students may have dealt extensively with atomic structure. Thus, to some students, this section may seem too "old hat." One important goal here is to clarify the student's understanding of atomic number and mass number.

Notice that isotopic notation is properly represented by $^{32}_{16}\mathrm{S}$ rather than $_{16}\mathrm{S}^{32}$. The upper right-hand corner is reserved for the net charge on the atom, if any.

Some students may express interest in the method by which Henry Moseley determined the number of protons in atoms of different elements. Moseley bombarded different metals with high-energy electrons. He then measured the wavelengths of X-rays that the metal emitted. He found that the wavelengths decreased in a regular pattern as the estimated nuclear charge on the metal atom increased. These estimated charges came from Rutherford's scattering experiments (see section *A-28 The Heart of the Matter*).

From these data on X-ray wavelengths, Moseley determined the exact nuclear charge in specific atomic nuclei. Knowing the charge of an electron, he was able to identify the number of protons associated with a specific atom.

While it is not necessary to dwell on unified atomic mass units, it is important for students to comprehend the tiny mass associated with the electron, and with the neutron, proton, and isolated atom, for that matter. You may wish to discuss our need to find convenient ways of expressing very small and very large quantities.

Some of your more advanced students might like to do research on Dr. Erwin Mueller's photograph of a tungsten crystal. This photograph was produced with the aid of the field ion microscope, which Mueller developed. Student research might include an explanation of why this photograph was so interesting to the scientific world and to many nonscientists in the early 1950's. Suggest that students check the *Reader's Guide to Periodical Literature* in their library for information sources. For instance, two articles dealing in part with Mueller's work appeared in *National Geographic* (September 1958, pp. 303–353; and February 1977, pp. 270–290).

Challenge your students to add to the chemistry cartoon collection by creating cartoons of their own and by bringing in any others found in current periodicals.

A-27 ISOTOPES: A WEIGHTY MATTER

The calculation of average atomic masses may cause some difficulty for students, especially those weak in computational skills. The chlorine exercise is intended to explain why masses reported on the periodic chart are not integral multiples of the standard mass, as might be expected. Use your judgment on how far to go with such calculations. The ability levels and goals of your students should be taken into consideration.

Here are the answers to the problems on page 50:

The Water Problem: There are 18 different water molecules possible. For a given oxygen isotope, there are six different combinations of hydrogen possible: HOH, HOD, HOT, DOT, TOT, DOD. Thus, for 3 different oxygen isotopes there are $3 \times 6 = 18$ possibilities. There are seven different masses of water molecules possible, ranging from 19 u through 24 u.

The Chlorine Problem: 77.5 percent $^{35}\mathrm{Cl}$ and 22.5 percent $^{37}\mathrm{Cl}$. This equation produces the answers: $35(x) + 37(100\text{-}x) = 35.45(100)$. (The 77.5 percent $^{35}\mathrm{Cl}$ and 22.5 percent $^{37}\mathrm{Cl}$ values mean that, on the average, in each 1000 atoms of chlorine samples in nature, 775 will be the $^{35}\mathrm{Cl}$ type and 225 will be the $^{37}\mathrm{Cl}$ isotope. Assure students that there are not fractional parts of atoms involved in these stated percentages!)

The Heart of Matter: A Nuclear Chemistry Module provides students with laboratory activities involving the use of radioactive isotopes. Students also will investigate the nuclear structure of atoms in greater detail when they study nuclear chemistry.

A-28 THE HEART OF THE MATTER

Here the work of another pioneer in atomic structure, Ernest Rutherford, is introduced. Lord Rutherford's experimental results and his analysis of them are examples of the interplay between observation and interpretation.

The calculation of the relative volumes of the nucleus and the atom (page 51) is not difficult. It can illustrate how setting up the general mathematical expression first leads to a shortcut; the problem can be simplified by cancellation before any values are substituted:

$$\frac{V^{\text{atom}}}{V^{\text{atom}}} = \frac{4/3\pi r^2}{4/3\pi r^2} = \frac{(r^{\text{atom}})^3}{(r^{\text{nucleus}})^3}$$

$$= \frac{(d^{\text{atom}})^3}{(d^{\text{nucleus}})^3} = \left(\frac{100\,000}{1}\right)^3 = 10^{15}$$

You may wish to share Rutherford's classic comment about his metal foil experiment with your class. He wrote, "It was quite the most incredible event that has ever happened in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." (It is estimated, by the way, that only one out of every ten thousand alpha particles bounced back in this fashion.)

Thus, *The Structure of Atoms* ends with the general model of a nuclear atom as outlined in this section. It should be apparent that, up to this point, not much has been said about how electrons are arranged around the nucleus. Electron arrangements, and their profound influence on chemical behavior and bonding, will be the focus of the *Chemical Bonding* section that follows later.

ANSWERS TO QUESTIONS

(Student module page 52)

1. (a) 14 p, 14 n, 14 e, 28 u; (b) 29 p, 34 n, 29 e, 63 u; (c) 50 p, 69 n, 50 e, 119 u; (d) 54 p, 77 n, 54 e, 131 u; (e) 94 p, 148 n, 94 e, 242 u
2. Twenty different kinds of NH_3 are possible.
3. For each unit volume occupied by nuclei, 10^{15} times this volume will be occupied by the electron clouds (see discussion of calculation in the teacher's guide *A-28*).

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Give the number of protons, electrons, and neutrons in a neutral $^{48}_{22}Ti$ atom.

   22 protons, 22 electrons, 26 neutrons

2. One isotope of Ha contains 105 protons, 105 electrons, and 155 neutrons. The correct symbol for this element is:

   A. $^{105}_{145}Ha$ B. $^{105}_{260}Ha$ C. $^{260}_{105}Ha$ D. $^{145}_{105}Ha$

3. The number of neutrons in an atom of $^{18}_{8}O$ is:

   A. 6 B. 1 C. 10 D. 26

The Language of Chemistry

Here the students will be learning the basic rules that govern the naming of simple compounds and the writing of chemical equations. The presentation in the module is far from exhaustive, but it establishes useful guidelines for naming compounds, writing formulas, and balancing equations. Students should have little difficulty in developing the rudimentary skills. The principles set forth here will serve as a sound foundation for the students' further work in chemistry as they move into other IAC modules.

Perhaps your students already are familiar with the methods that are used to name compounds. Perhaps they have learned to write and balance chemical equations in their earlier study of science. If your students have demonstrated proficiency in these areas, you may elect to skip this section. Or, as a second option, you might move directly to *The Mole Concept*, teaching portions of *The Language of Chemistry* as time allows in subsequent class sessions. The choice is yours.

In any event, we hope that these basic skills are reviewed and highlighted throughout your chemistry course. As in the case of almost every skill, familiarity and proficiency come through day-to-day use, not through a one-time intensive exposure. Plan on reviewing the skills developed in this section on later occasions when students are called upon to name a compound or balance an equation.

If you can secure copies of foreign chemistry journals, show your students examples similar to the Japanese chemistry text on page 53 of the universal language of chemical symbols and formulas.

A-29 WHAT'S IN A NAME?

As is apparent from the student module, we do not emphasize or feature the dated -ic/-ous convention for naming compounds that include metallic elements with variable charges. The time has arrived when this ambiguous classical system has outlived it usefulness. Consistent application of the internationally accepted IUPAC system nomenclature (including the Stock system detailed in this portion of the student module) is a feature of the IAC program.

The term *ion* is introduced here because it is associated with a convenient method for naming ionic compounds. At this point, the student is well served by a simple definition of an ion as given in the module. For the present, do not go into details of bonding, valence shells, and electron arrangements. These topics are treated later in *Chemical Bonding*.

Your students already will be familiar with the names of the simple compounds referred to in this section (e.g., sodium chloride). You can easily work the names of familiar compounds into the general naming scheme that is explained here. Depending on your own style of teaching, you may even offer some chemical humor to lighten this section. All chemistry teachers have their favorities. Here are some examples:

1. What is overtime pay for police officers?
   Answer: $Cu(NO_3)_2$ ("copper nite rate").
2. What is H?
   Answer: Hydrogen.
   What is H_2?
   Answer: Hydrogen gas.
   What is H_2O?
   Answer: Water.
   What is H_2O_2?
   Answer: Hydrogen peroxide.
   What is H_2O_4?
   Answer: *For* drinking, *for* washing, and *for* many other purposes!
3. Translate this: $\frac{2NaCl(aq)}{C_7}$.
   Answer: Saline, saline, over the seven C's!
4. What is $(BEr)_8$?
   Answer: Either the month after September or eight people sitting in ice water.

Once you start this, students will make valiant efforts to devise other chemical puns. Numbers 3 and 4 came from just such friendly teacher-student rivalry. No harm is done. In fact, students unconsciously learn useful chemical language as they puzzle over ways to construct more chemical puns.

Note: Ionic charges are written in the IAC modules in the "2+" form, consistent with accepted IUPAC guidelines, rather than in the "+2" form. The "+2" style is still common in many chemistry textbooks, but we feel there is an advantage in using a form that is agreed upon internationally. You will find that students easily adjust to either format.

Answers to the naming problems presented on page 55:

H_2S = hydrogen sulfide
LiF = lithium fluoride
PbI_2 = lead iodide
MgO = magnesium oxide

Answers to the naming problems presented on page 57:

$FeCl_2$ = iron(II) chloride
$BaCl_2$ = barium chloride
CuI = copper(I) iodide
SnF_2 = tin(II) fluoride
SnF_4 = tin(IV) fluoride
Cu_2S = copper(I) sulfide

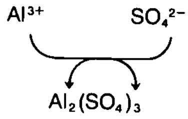
NH_4Cl = ammonium chloride
$HgCO_3$ = mercury(II) carbonate
$AgCH_3COO$ = silver acetate
$Fe(SCN)_3$ = iron(III) thiocyanate
$(NH_4)_2Cr_2O_7$ = ammonium dichromate
$Zn_3(PO_4)_2$ = zinc phosphate

A-30 WRITING FORMULAS

The material in this section is a logical extension of what was just discussed in *A-29 What's in a Name?* Here students gain experience in writing correct formulas for ionic compounds, given their names. The principle of insuring that each compound's formula represents zero total electric charge will probably need some amplification in class. With students relatively weak in arithmetic, your biggest hurdle will be in helping them to add signed numbers to confirm, for example, that aluminum sulfate represents a +6 and −6 ion combination.

This section devotes some time to explaining the significance of parentheses, as in the contrast of $CaOH_2$ with $Ca(OH)_2$. This has always been a confusing point for many students—be sure the *meaning* of both expressions is clear. It will be necessary to spend some class discussion time on this topic.

One of the time-saving hints suggested in the module is the commonly invoked trick of "crossing" the ionic charges in writing a correct ionic formula. This example will illustrate the approach:



If you use such an approach in your teaching of formula writing, try to make the *basis* for the time-saving (and thought-saving!) clear to students. Make sure they know why it works. Unless adequate background is provided, thoughtless application of this time-saver could lead to awkward expressions, such as Mg_2O_2 for magnesium oxide. As usual, apply those teaching methods and strategies that you have found successful with your students. And be sure you provide practice with these skills throughout your chemistry course.

Here are answers to the formula-writing exercises given on page 59:

zinc nitrate = $Zn(NO_3)_2$
copper(I) carbonate = CU_2CO_3
potassium iodide = KI
magnesium bromide = $MgBr_2$
sodium hydrogen carbonate = $NaHCO_3$ (baking soda)
lead sulfide = PbS

A-31 THE BALANCING ACT

In a chemical reaction, atoms must be conserved (a requirement of nature). The conservation of matter is the underlying principle on which the writing of equations is based. Once your students understand this principle, they will see why an equation that is correctly written must be a balanced equation. Whatever our language, the operation remains the same.

Skill in writing equations comes through practice. As in the examples given in the module, many practice problems should be assigned in word form to give students practice in translating the sentences into chemical notation.

Caution: Reference is made on page 62 of the student module to the thermal decomposition of potassium chlorate ($KClO_3$) as an equation-balancing exercise. Despite the fact that such a decomposition (using MnO_2 as a catalyst) has been presented for decades in textbooks as a common laboratory method for oxygen preparation, you should be warned that the reaction is extremely hazardous. *Potassium chlorate can react explosively if placed in contact with oxidizable substances, and the generator conventionally used for the oxygen preparation can become plugged, causing the flask to explode during the heating step.* Our recommendation is that you *not* conduct this reaction! (Experiment *A*-32 will illustrate a recommended reaction for O_2 preparation.)

This section leads directly to *A*-32, a three-part experiment, which ties in pencil-and-paper work on equation writing with laboratory realities. Further equation-writing practice can be designed to follow completion of the experiment.

EXPERIMENT
A-32 FROM REACTIONS TO EQUATIONS

In this experiment students prepare three common gases—H_2, O_2, and CO_2—through simple chemical reactions. Some characteristics of the three gases are compared, and students are asked to write balanced equations to express the chemistry observed.

Concepts

- Information contained in balanced chemical equations is based on laboratory observations and data.

- Gases can be distinguished on the basis of their characteristic properties.

Objectives

- Write a balanced equation, given laboratory observations concerning the reactants and products of a simple chemical reaction.
- Distinguish samples of oxygen, hydrogen, and carbon dioxide gas on the basis of their characteristic properties.

Estimated Time One period

Student Grouping Pairs

Materials

400 cm³ 1 M hydrochloric acid (HCl)
200 cm³ 3 percent hydrogen peroxide (H_2O_2)
500 cm³ saturated calcium hydroxide [$Ca(OH)_2$], (limewater)
50 g marble chips ($CaCO_3$)
10 g manganese dioxide (MnO_2)
10 g zinc (Zn), granular or mossy
10 g copper(II) sulfate, pentahydrate ($CuSO_4 \cdot 5H_2O$)
30 18 × 150-mm test tubes
15 50-cm³ or 100-cm³ beakers
15 stopper-tubing assemblies
wood splints

Advance Preparation To prepare solutions, add each solute to enough distilled water to give you the required amount of each solution:

400 cm³ 1 M HCl: 33 cm³ conc. HCl per 400 cm³ solution
200 cm³ 3% H_2O_2: If preparing from 30% H_2O_2, use 20 cm³ 30% H_2O_2 per 200 cm³ solution.
500 cm³ limewater [saturated $Ca(OH)_2$]: 0.8 g $Ca(OH)_2$ per 500 cm³ solution. When saturated, allow excess solute to settle. Filter or decant clear saturated limewater prior to use.

Prepare the stopper-tubing assemblies needed for CO_2 generation.

Prelab Discussion Make the transition from pencil-and-paper equation balancing to this activity by stressing the fact that chemistry is an experimental science. Ultimately, all chemical knowledge is acquired through experimentation; the equations we write are viewed as useful because they provide a capsule, symbolic summary of observed reactions.

Since this experiment is qualitative in nature, assure students that high-precision measurements are not necessary for success.

Laboratory Tips *Part I—Preparing Hydrogen Gas* The tube mouth must be *loosely* covered to prevent pressure build-up while hydrogen gas is being evolved. However, since hydrogen is considerably less dense than air, the cover is necessary to prevent the accumulated hydrogen (H_2) from fully escaping from the tube. A mixture of hydrogen (H_2) with air (O_2) is necessary for the characteristic "pop" that is observed here.

Scratch-free test tubes are advised, to prevent the slight chance of a weakened tube breaking during the splint test.

The $CuSO_4$ does not participate directly in the formation of H_2 but does enhance the rate of the acid-zinc reaction, probably by action of Cu^{2+} on the surface of zinc (Zn) via an oxidation-reduction reaction. A curious student may be interested in trying the reaction *without* the presence of copper(II) sulfate, to make the comparison.

Part II—Preparing Oxygen Gas Reasonably fresh hydrogen peroxide (H_2O_2) solution is necessary to produce the desired reaction; bench-test your stock of H_2O_2 solution prior to lab to insure success.

The action of MnO_2 as a catalyst here will probably intrigue students, although there is no simple explanation for its effect on this specific change. It is worth pointing out that H_2O_2 decomposes by itself *slowly* to form water and oxygen gas; the MnO_2 simply speeds up a reaction that already is at work in the solution.

Since the density of oxygen (O_2) is comparable to the density of air, there is less concern about covering the open end of the tube than there was in *Part I* with hydrogen (H_2).

Part III—Preparing Carbon Dioxide Gas This reaction foreshadows experiment *A-37 Concentration of Solutions,* where a similar marble chip–hydrochloric acid reaction will lead to an understanding of molar concentration (M). Some students will recall earlier limewater experiments in previous science classes. Don't be surprised if some students seek permission to bubble their exhaled breath through a fresh limewater sample. If time permits, such observations can be useful for your postlab discussion. Consider having a few clean drinking straws on hand for this purpose; do not permit students to exhale through the stopper-tubing assembly, however.

Range of Results *Part I* Hydrogen gas produced a characteristic "pop" in the presence of the burning wood splint. These two equations apply:

1. $Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$
2. $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$

Part II The glowing wood splint burst quickly into flame in the presence of oxygen gas. (The bursting into flame may be viewed by some students as being almost explosive, since some noise is often observed. Direct their attention to the fact that the splint emerges aflame here, while in *Part I* the lighted splint is extinguished by the "pop.") This equation applies:

$2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$
("MnO_2" can be placed above the arrow to indicate its presence as a catalyst.)

Part III The limewater (calcium hydroxide solution) turned milky or cloudy when carbon dioxide gas was bubbled through it. The burning wood splint is extinguished when placed in the carbon dioxide generator tube. These two equations apply:

1. $CaCO_3(s) + 2HCl(aq) \longrightarrow CO_2(g) + CaCl_2(aq) + H_2O(l)$
2. $CO_2(g) + Ca(OH)_2(aq) \longrightarrow CaCO_3(s) + H_2O(l)$

Postlab Discussion Along with the discussion of the balanced equations that describe the reactions carried out, you have opportunities to introduce a variety of relevant themes related to the chemistry shown in this experiment. Here are a few ideas:

- Use of hydrogen gas (H_2) as a "clean" fuel, since water vapor is the only combustion product. You may wish to encourage students to complete a research report on the so-called hydrogen economy, for example.
- Use of the hydrochloric acid–marble chip reaction as a quick field test for the presence of a carbonate-containing rock in field geology.
- Application of the ability of carbon dioxide to extinguish fire (CO_2 fire extinguishers).
- Observing that the product of the limewater test ($CaCO_3$ precipitate) is simply the original marble chip in a different physical form. Some students may be interested in recovering some of the solid $CaCO_3$ precipitate, drying it, and seeing if it also reacts with hydrochloric acid. Why does it react more rapidly? (larger surface area)
- Relative densities of common gases, such as H_2, O_2, and CO_2. Later in the module, when molar masses of substances are discussed, you may wish to come back to the qualitative observations about density made in this experiment.

Here are answers to the problems detailed on page 64 of the student module:

Burning gasoline: $C_8H_{18} + \frac{25}{2}O_2 \longrightarrow 8CO_2 + 9H_2O$

or:

$2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O$

Ammonia synthesis: $3H_2 + N_2 \longrightarrow 2NH_3$

Sulfur dioxide use: $2SO_2 + 5C \longrightarrow CS_2 + 4CO$

Rocket propulsion: $2N_2H_4 + N_2O_4 \longrightarrow 3N_2 + 4H_2O$

Challenge your students to come up with other simple situations similar to the four listed on page 64. These should be chemical changes that can be put easily into the form of an equation. Then try writing and balancing the equations as a class project.

ANSWERS TO QUESTIONS

(Student module pages 64–65)

1. (a) sodium iodide; (b) iron(II) hydroxide; (c) calcium sulfate; (d) silver sulfide; (e) potassium permanganate; (f) nickel perchlorate; (g) cesium carbonate; (h) ammonium hydrogen sulfate (or ammonium bisulfate)
2. (a) potassium thiocyanate; (b) lead nitrate; (c) lithium oxide; (d) barium thiosulfate; (e) tin(II) dihydrogen phosphate; (f) sodium hydrogen carbonate (or sodium bicarbonate); (g) sodium carbonate; (h) copper(II) hydroxide
3. iodate and bromate
4.

NH_4NO_3	$Ba(NO_3)_2$	$Al(NO_3)_3$
$(NH_4)_2SO_4$	$BaSO_4$	$Al_2(SO_4)_3$
$(NH_4)_3PO_4$	$Ba_3(PO_4)_2$	$AlPO_4$

5. (a) $PbCr_2O_7$; (b) Ag_2O; (c) $Fe(NO_3)_3$; (d) $Ca(ClO)_2$; (e) $Mg(ClO_4)_2$; (f) K_2SO_3; (g) $Cr_2(SO_4)_3$; (h) ZnI_2

6. (a) $NaOH$; (b) $LiMnO_4$; (c) $CuCl_2$; (d) $Al(CH_3COO)_3$; (e) $Ba_3(PO_4)_2$; (f) NH_4F; (g) $Hg(ClO_3)_2$; (h) $Sn(CrO_4)_2$
7. (a) 1, 3, 2, 3; (b) 2, 1, 2; (c) 1, 3, 1, 2; (d) 2, 1, 2, 1
8. $6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$
9. $Mg + 2HCl \longrightarrow MgCl_2 + H_2$
10. $2Ca_3(PO_4)_2 + 6SiO_2 + 10C \longrightarrow 6CaSiO_3 + 10CO + P_4$

EVALUTION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Balance the following equations:

A. $\underline{\ 4\ }\,Cr(s) + \underline{\ 3\ }\,O_2(g) \longrightarrow \underline{\ 2\ }\,Cr_2O_3(s)$

B. $\underline{\ 1\ }\,Zn(s) + \underline{\ 2\ }\,HCl(aq) \longrightarrow \underline{\ 1\ }\,ZnCl_2(aq) + \underline{\ 1\ }\,H_2(g)$

C. $\underline{\ 2\ }\,C_2H_6(g) + \underline{\ 7\ }\,O_2(g) \longrightarrow \underline{\ 4\ }\,CO_2(g) + \underline{\ 6\ }\,H_2O(g)$

2. The formula for sodium oxide is:

A. NaO B. Na_2O C. Na_2O_2 D. NaO_2

3. Aluminum sulfate is correctly written as:

A. $AlSO_4$ B. $Al_3(SO_4)_2$ C. $Al(SO_4)_2$ D. $Al_2(SO_4)_3$

4. A fluorine disposal plant makes use of the following two reactions to dispose of excess fluorine. Use is then made of the products of the reactions:

$\underline{\ 2\ }\,F_2 + \underline{\ 4\ }\,NaOH \longrightarrow \underline{\ 1\ }\,O_2 + \underline{\ 4\ }\,NaF + \underline{\ 2\ }\,H_2O$

$\underline{\ 2\ }\,NaF + \underline{\ 1\ }\,CaO + \underline{\ 1\ }\,H_2O \longrightarrow \underline{\ 1\ }\,CaF_2 + \underline{\ 2\ }\,NaOH$

Balance the above equations.

5. Phthalic anhydride ($C_8H_4O_3$), which is used in great quantity by the plastics industry, is produced by controlled oxidation of naphthalene ($C_{10}H_8$). Balance the following equation for the production of phthalic anhydride.

$\underline{\ 2\ }\,C_{10}H_8 + \underline{\ 9\ }\,O_2 \longrightarrow \underline{\ 2\ }\,C_8H_4O_3 + \underline{\ 4\ }\,CO_2 + \underline{\ 4\ }\,H_2O$

(Note: The above is more difficult than the others!)

6. Hydrochloric acid (HCl) makes up most of the "drip, drip, drip" of excess stomach acid felt by many suffering individuals. Plain baking soda (sodium bicarbonate, $NaHCO_3$) will neutralize the acid, forming carbon dioxide, water, and some sodium chloride. For the sake of many pained stomachs, write a balanced equation showing how HCl is destroyed by baking soda.

$HCl + NaHCO_3 \longrightarrow CO_2 + H_2O + NaCl$

The Mole Concept

Atoms are so tiny and a mole is so large that it is difficult for students to gain any real feeling for the magnitude or significance of the mole. The passel is presented here as a hypothetical counting unit. It is an invented term with an appealing ring that students can readily comprehend. Hence, it establishes a useful introduction to the mole concept. Your students will learn through experience with a passel how an established mass can represent a fixed number of objects. In applying the notion of a passel, students will be working with peas and rice, not with invisible atoms and molecules, which makes the meaning of the concept more concrete.

Once your students "see" that a relationship exists between the number of things and a measurable mass, they can apply the same notion to gain some understanding of how chemists use the mole to deal with large numbers of submicroscopic atoms or molecules. Then you can explain the relationship of moles to formula-writing, the interpretation of equations, and the concentration of solutions. One idea leads to the next in a logical order. The passel serves as a unit for counting peas and rice. The mole is useful for counting atoms and molecules. The mole (expressed as *mol*) has been officially accepted as one of the seven base units of the modernized metric system (SI), expressing the amount of substance. How have chemists learned to count the billions of atoms that enter into a reaction? The answer to this question is developed in the narrative that follows. Treat this as a prelab introduction to miniexperiment *A-33 What's the Count?* Your students will establish a relationship between mass and a numerical quantity by doing the experiment.

MINIEXPERIMENT
A-33 WHAT'S THE COUNT?

The purpose of this miniexperiment is to illustrate a method for indirectly counting a large number of particles. Here students will be working with peas and rice, but they will be applying the same principle in this counting exercise as that which chemists apply to their counting of atoms. The miniexperiment provides background for an understanding of the mole concept.

Concept

- Large numbers of uniform particles can be counted by determining their mass.

Objective

- Determine the number of particles in a large set of uniform particles, given the average mass of one particle.

Estimated Time One period

Student Grouping Pairs

Materials

450 g dried peas (whole)
225 g rice
15 150-cm^3 beakers
balances (0.1 g to 0.01 g sensitivity)
Note: Other granular materials can also be used—unpopped popcorn, dried beans, and the like will work equally as well.

Advance Preparation None

Prelab Discussion Pose the general problem of how one would count large numbers of uniform particles. Move into the laboratory activity quickly. The experiment teaches the lesson.

Laboratory Tips Caution the students to discard any split peas or split rice grains. At your discretion, students can either continue working on short problems at their lab benches or return to their desks for the written activity.

Range of Results The average mass of a dried pea ranges from about 0.20 g to 0.30 g, depending on its variety and source. The mass of 100 dried peas will be between 20 g to 30 g. If your sample is relatively uniform, you will find remarkable agreement among students on the mass of 100 peas. The mass of 1000 peas would be between 200 g and 300 g, again depending on the source of the peas. An average rice grain has a mass of 0.01 g to 0.02 g, also depending upon the source.

Postlab Discussion The postlab discussion should lead rather directly and quickly into section *A-34 Passels of Peas*. There we define the passel and apply it to the results of the experiment. This experiment seems to be easily understood by nearly all students. Any lab write-up should be delayed until *A-34* is covered, since there are questions raised in *A-34* that pertain to *A-33*. Note: Prospective pea-shooters should be reminded that the study of pea trajectory is reserved for physics class.

A-34 PASSELS OF PEAS

Note that the definition of a passel is simply constructed for convenience; the term has no deeper significance. The notion of units (dimensional analysis) should be stressed. Throughout this section students should be reminded of the fundamental idea: We are relating the number of items in a collection to the mass of the collection.

The usefulness of this "counting by weighing" idea was illustrated in practical terms in the early days of the IAC project. Each teacher testing the IAC program needed 150 special answer sheets. These sheets arrived in boxes of 500, however. We began patiently counting out piles of 150 answer sheets. Finally, one tired, resourceful worker discovered that a 0.1 g sensitivity platform balance, set to the mass of 150 answer sheets, could "count" subsequent bundles of answer sheets to 150 ± 1 sheet. What we teach the students actually works!

Note that our application of the term "passel" in the problems in this section is close to the manner in which a chemist uses the mole concept. The four questions on page 69 have answers that naturally depend on the specific data collected for the peas and rice used in miniexperiment *A-33*.

Sample calculations are shown here:

Basis: 1 passel rice = 15.5 g
1 passel peas = 280 g
(These two values will vary, depending upon the samples used.)

1. 15.5 g rice per passel; 280 g peas per passel
2. 7.00 passels of particles are in the mixture

$$3.00\ \cancel{\text{passels rice}} \times \frac{15.5\text{ g rice}}{1\ \cancel{\text{passel rice}}} = 46.5\text{ g rice}$$

$$4.00\ \cancel{\text{passels peas}} \times \frac{280\text{ g peas}}{1\ \cancel{\text{passel peas}}} = 1120\text{ g peas}$$

Thus, total mass = 1120 g + 46.5 g = 1166 g

3. $500.0\ \cancel{\text{g rice}} \times \dfrac{1\text{ passel rice}}{15.5\ \cancel{\text{g rice}}} = 32.2\text{ passels rice}$
4. 500.0 g rice = 32.2 passels rice

6 rice grains per pea = 6 passels rice per passel peas

$$\text{Total passels of peas needed} = \frac{32.2}{6} = 5.37\text{ passels peas}$$

$$5.37\ \cancel{\text{passels peas}} \times \frac{280\text{ g}}{1\ \cancel{\text{passel peas}}} = 1510\text{ g peas needed}$$

A-35 PASSELS AND MOLES

We now establish the connection between what the students have learned about passels and the mole concept. The module explains the rationale for "choosing" 6.02×10^{23} units per mole. The mole relates not only to the number of atoms but to the atomic mass as well; it signifies an amount of substance counted in either numbers or mass. The term mole can be correctly used for ions, electrons, molecules, or any other kind of particle.

The interpretation of a chemical equation in terms of moles is illustrated in the summary on page 70. Plan on illustrating this interpretation of a chemical equation with further examples taken from previous sections *(A-22, A-31)* or with other examples of your own choosing. Do this before going on the next section on molar mass. Since mass relationships are treated in the next section, the last "meaning" of the chemical equation listed in the summary on page 70 (mass of reactants and products) will not require emphasis here.

For the record, here's the basis for the "outlandish" mole analogy given in the text concerning a mole of pennies:

Assumptions:
Earth circumference = 40 000 km = 4.0×10^4 km
= 4.00×10^9 cm
Distance to Moon = 385 000 km = 3.85×10^5 km
= 3.85×10^{10} cm
Cost of gasoline = 17.2¢ per liter (65¢ per gallon)
Gasoline consumption = 6.4 km per liter (15 mpg)
U.S. Population = 220 000 000 = 2.2×10^8

Given: 6.022×10^{23} pennies, or \$$6.022 \times 10^{21}$

Total kite string bought at \$$10^6$ per cm:

$$\cancel{\$}6.022 \times 10^{21} \left(\frac{1\text{ cm string}}{\cancel{\$}10^6}\right) = 6.022 \times 10^{15}\text{ cm string}$$

Winding string around Earth 10^6 times:

$$10^6\ \cancel{\text{circuits}} \left(\frac{4.00 \times 10^9\text{ cm}}{1\ \cancel{\text{circuit}}}\right)$$

$= 4.00 \times 10^{15}$ cm string used

To Moon and back 2.0×10^4 times:

$$2.0 \times 10^4\ \cancel{\text{trips}} \left(\frac{7.70 \times 10^{10}\text{ cm}}{1\ \cancel{\text{trip}}}\right)$$

$= 1.54 \times 10^{15}$ cm string used

Total string used = $(4.00 \times 10^{15}\text{ cm}) + (1.54 \times 10^{15}\text{ cm})$
$= 5.54 \times 10^{15}$ cm

Total string remaining = $(6.022 \times 10^{15}\text{ cm}) - (5.54 \times 10^{15}\text{ cm})$
$= 0.48 \times 10^{15}$ cm

Selling remaining string at \$0.01 per cm:

$$0.48 \times 10^{15}\ \cancel{\text{cm}} \left(\frac{\$0.01}{1\ \cancel{\text{cm string}}}\right)$$

$= \$0.48 \times 10^{13} = \$4.8 \times 10^{12}$

Cost of 2.2×10^8 automobiles at \$$4.000 \times 10^3$ per auto:

$$2.2 \times 10^8\ \cancel{\text{autos}} \left(\frac{\$4.000 \times 10^3}{1\ \cancel{\text{auto}}}\right)$$

$= \$8.8 \times 10^{11} = \$0.88 \times 10^{12}$

Funds remaining = $(\$4.8 \times 10^{12}) - (\$0.88 \times 10^{12})$
$= \$3.9 \times 10^{12}$

Cost of driving 2.2×10^8 autos nonstop for 1 day (24 hours):

$$24\,\cancel{\text{h}}\left(\frac{90\,\cancel{\text{km}}}{1\,\cancel{\text{h}}}\right)\left(\frac{\cancel{1\text{ liter}}}{6.4\,\cancel{\text{km}}}\right)\left(\frac{\$0.172}{1\,\cancel{\text{liter}}}\right)(2.2 \times 10^8)$$

$$= \$1.27 \times 10^{10}/\text{day}$$

Total days autos can be driven:

$$\$3.9 \times 10^{12}\left(\frac{1\text{ day}}{\$1.27 \times 10^{10}}\right)$$

$$= 307\text{ days, or 10 months (!)}$$

The above calculations are an excellent exercise in exponential notation and dimensional analysis, but are probably beyond the range of many chemistry students. The figures are placed here only for your reference and amusement. The original version of the kite string story is credited to a Richfield High School (Minnesota) chemistry student who created it in the mid-1960's as a personal attempt at fathoming the awesome magnitude of a mole.

Miniexperiment Challenge students who are mathematically inclined to devise additional means of illustrating the size of a mole to supplement the illustration found in the module.

The photographs of a drop of water on pages 69–70 should provoke some discussion as well as challenge the observation skills of your students. After discussion, ask interested students to try this, using a medicine dropper or dropping pipette. These photographs were taken with a high-speed camera. Not many of us have developed our observation skills to the point of actually seeing all of this happen as a drop of water falls on a flat surface. Try it and see!

A-36 MOLAR MASS

This section focuses on the relationship between moles and atomic and molecular masses. Given the correct formula of a compound, students should have little difficulty in determining the molar mass of the compound. Some might wonder where the numbers come from. Once they become familiar with the periodic chart, this problem will be overcome.

The term *molar mass* refers to the mass of one mole of units, whether these units are atoms, molecules, or ionic species such as NaCl. This term avoids awkward and confusing distinctions between "formula weight" and "molecular weight" that have appeared in many earlier books. Now that the mole has been officially adopted as an SI base unit, terms such as molar mass will become more familiar and common in scientific work.

Diatomic molecules sometimes cause confusion. It might be necessary to stress the difference between an atom of, say, chlorine (Cl) and a molecule of chlorine (Cl_2). Point out that substances that exist naturally in molecular form (e.g., chlorine) will be written as molecules when used in equations.

The spilling of sodium hydroxide shows the relationship between a chemical formula, molar mass, and moles. Go through this example carefully, explaining the reasons for each step and how each is related to concepts covered in previous sections. Commercial vinegar contains only about 5 percent acetic acid. Thus the calculation shown in the module gives the mass of "active ingredient" required. This mass of vinegar needed would be 360 g/0.05 = 7200 g. Remind students of previous percent composition work in experiment *A-10 Investigating a Simple Mixture*. The idea of expressing concentration as a percentage leads to the section on concentration of solutions, which follows.

These are the molar masses that students are asked to calculate on page 71 of the student module (all carry units of g/mol).

(a) 63.5
(b) 207.2
(c) 17.0
(d) 100.1
(e) 40.0
(f) 187.5
(g) 342.0 (if H is taken as 1.008, this molar mass would be 342.2)
(h) 58.5

Here are the answers to the problems on page 72:

1. 2 mol × 23.0 g/mol = 46.0 g sodium (Na)

2. 71.0 g chlorine (Cl)

3. 2 mol × 58.5 g/mol = 117 g sodium chloride (NaCl)

4. $46\,\cancel{\text{g}} \times \frac{1\text{ mol Na}}{23.0\,\cancel{\text{g}}} = 2.0\text{ mol sodium (Na)}$

5. $2Na + Cl_2 \longrightarrow 2NaCl$

$$2.0\ \cancel{\text{mol Na}} \times \frac{1\ \text{mol}\ Cl_2}{2\ \cancel{\text{mol Na}}} = 1.0\ \text{mol}\ Cl_2$$

6. 1.0 mol × 71.0 g/mol = 71 g Cl_2 needed

EXPERIMENT
A-37 CONCENTRATION OF SOLUTIONS

This experiment introduces the concept of molar concentration (molarity), using ideas developed in previous sections. Earlier, the mole concept was related to number of atoms or molecules, molar mass, and chemical equations. In this experiment, it is shown to relate also to the concentration of a solution. Students can now begin to recognize how useful the mole concept really is to a chemist.

Concepts

- Solution reactions can be interpreted in terms of moles just as these relationships can be stated for nonsolution reactions (pure gases, liquids, solids).
- The concentration of a solution may be expressed as moles of solute per liter of solution, which defines the molar concentration (molarity).

Objectives

- Calculate the molar concentration of a solution, given laboratory data similar to that obtained in this experiment, or data on the volume of a solution and the amount of solute dissolved.
- Write balanced equations for reactions such as the one between calcium carbonate and hydrochloric acid.
- Analyze the mass relationships in a chemical reaction in terms of basic mole relationships of the reacting substances and products.

Estimated Time One-fourth period for prelab discussion; one period for lab work; one period for postlab discussion.

Student Grouping Pairs

Materials

50 g marble chips ($CaCO_3$)
1500 cm^3 0.50 M hydrochloric acid (HCl)
400 cm^3 acetone
15 250-cm^3 beakers
15 100-cm^3 graduated cylinders
15 funnels
filter paper

Advance Preparation Prepare the 0.50 M hydrochloric acid solution by diluting 62.5 cm^3 concentrated (12 M) hydrochloric acid taken from a freshly opened bottle to make 1500 cm^3 total solution. Follow safe procedures; add the acid slowly to the water as you stir.

Prelab Discussion Begin your discussion with some brief stage-setting along the lines of the conclusion to section *A-36 Molar Mass* in the student module. The purpose of this experiment is to "discover" the molar concentration relationship from the class data obtained.

Laboratory Tips Heat the hydrochloric acid solution to a point just short of boiling. This allows students to keep track of the carbon dioxide (CO_2) evolution in the reaction. Vigorous boiling "masks" the gas evolution; students cannot judge when the reaction is finished. **Caution:** *Be sure Bunsen burners are off before using acetone.*

Vary the volume of hydrochloric acid that you assign to students. Assign some pairs 30.0 cm^3, others 40.0 cm^3, others 50.0 cm^3, others 60.0 cm^3, and others 70.0 cm^3. Assign each of these volumes to assure a range of results.

Range of Results Sample calculations:
Volume 0.50 M HCl taken = 50.0 cm^3 = 0.0500 liter
Initial mass $CaCO_3$ = 2.48 g
Final mass $CaCO_3$ = 1.26 g
Mass $CaCO_3$ "lost" = 2.48 g − 1.26 g = 1.22 g
Equation for reaction: $2HCl + CaCO_3 \longrightarrow CO_2 + H_2O + CaCl_2$

a. Moles $CaCO_3$ reacted:

$$1.22\ \cancel{g\ CaCO_3} \times \frac{1\ \text{mol}\ CaCO_3}{100\ \cancel{g\ CaCO_3}}$$
$$= 0.0122\ \text{mol}\ CaCO_3$$

b. Moles HCl needed to react with $CaCO_3$
= 2 × 0.0122 mol
= 0.0244 mol HCl

$$\text{Thus: } M = \frac{0.0244\ \text{moles HCl}}{0.0500\ \text{liters}} = 0.488\ M\ HCl$$

The calculated mole/liter ratio for each pair of students should be reported and compared. Students can help to determine the mean and median value for this ratio for use in the postlab discussion. Individual student results for the mole/liter ratio (molarity) will probably vary from about 0.40 to 0.60, but the central value for grouped class results will be very close to 0.50.

Postlab Discussion Students should recognize that almost all lab pairs obtained a calculated ratio close to the 0.50 M value declared on the bottle of hydrochloric acid. Discuss some of the immediate implications of this useful concentration unit: Regardless of the quantity of hydrochloric acid originally taken, or the amount of calcium carbonate (marble) reacted, the "moles solute/liters solution" expression is essentially the same. It is a convenient way of expressing the amount of material dissolved in a solution, since it is closely tied to the fundamental mole concept.

A possible extension of the discussion with more advanced students could lead to noting that every reaction is limited by the reactant which is depleted first. Given the reactant amounts (and the balanced equation), application of the mole concept allows a student to make a judgment as to which reactant limits the amount of product that can be formed. The other reactant is left over as excess, as in the case of extra calcium carbonate (marble chips) here.

Miniexperiment Students can use the molarity concept to predict the actual amount of calcium carbonate ($CaCO_3$) that should react with other volumes of hydrochloric acid (HCl) not used in the procedure (e.g., 20.0 cm^3 or 80.0 cm^3). After calculating the "mass loss" of the marble chips expected, a student may wish to run the trial to verify the prediction.

The text on page 74 of the student module, following experiment *A-37*, provides a brief overview of molar concentration and allows student practice with this important expression through four sample problems. Try to tie work with molar concentration directly to the definition of this unit.

Answers to the four problems:

1. The result will depend on the volume of HCl assigned to the student. Assuming that 40.0 cm^3 HCl were assigned, for example, the student would find that the number of moles of HCl in *twice* this volume (80.0 cm^3) would be *twice* the number of moles of HCl calculated for the trial completed (shown as step b in the sample calculations for experiment *A-37* in this Guide).
2. $\left(\frac{0.50 \text{ mole HCl}}{1 \cancel{\text{liter}}}\right) 120\,000 \cancel{\text{liter}} = 60\,000 \text{ mole HCl}$
   $= 6.0 \times 10^4 \text{ mole HCl}$
3. $\left(\frac{1 \text{ liter}}{0.50 \cancel{\text{mole HCl}}}\right) 0.30 \cancel{\text{mole HCl}} = 0.60 \text{ liters}$
4. $\left(\frac{1 \text{ mole NaOH}}{40.0 \cancel{\text{g NaOH}}}\right) 60.0 \cancel{\text{g NaOH}} = 1.50 \text{ mole NaOH}$

$$M = \frac{\text{mole NaOH}}{\text{liter solution}} = \frac{1.50 \text{ mole}}{3.00 \text{ liter}} = 0.500 \text{ M}$$

ANSWERS TO QUESTIONS

(Student module page 74)

1. (All have units of g/mol)
   (a) 80.1; (b) 17.0; (c) 111.1; (d) 44.0 (44.1 if H taken as 1.008); (e) 82.0
2. (a) 120.0 g; (b) 15 g; (c) 6.02×10^{24} molecules; (d) 6.02×10^{23} O atoms
3. 0.20 mol HCl is present; this will react with 0.10 mol $CaCO_3$. 0.10 mol $CaCO_3$ has a mass of about 10 g (10.01 g).
4. A sample of N_2 with a mass of about 9×10^{-18} g would contain this many molecules. (Such a mass is impossible to detect by conventional means, however! An alternative might be to measure the N_2 gas volume, but this discussion would carry students beyond the scope of this module.)

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. The number of moles of oxygen atoms in one mole of $NaNO_3$ is:

   A. 1 B. 3 C. 1.5 D. 5

2. $2AgO(s) \rightarrow 2Ag(s) + O_2(g)$

   Molar mass Ag = 108 g/mol
   Molar mass O = 16.0 g/mol

   A. How many moles of AgO are there in 24.8 g AgO?

   $$24.8 \cancel{\text{g AgO}} \left(\frac{1 \text{ mol AgO}}{124 \cancel{\text{g AgO}}}\right) = 0.200 \text{ mol AgO}$$

B. How many moles of O_2 molecules can be made from that many moles of AgO?

$$\boxed{0.200\,\cancel{\text{mol AgO}}\left(\frac{1\text{ mol }O_2}{2\,\cancel{\text{mol AgO}}}\right) = 0.100\text{ mol }O_2}$$

3. If a beaker can hold 1.5 passels of potatoes and there are 300 potatoes/passel and the average mass of a potato is 10.5 g, what would be the total mass of potatoes that can be placed in the beaker?

[✓ A.] 4725 g   B. 450 g   C. 3150 g   D. 3600 g

4. The mass of 1 mole of *n*-butyl phthalate, $C_6H_4[COO(CH_2)_3CH_3]_2$ is:

A. 236 g   B. 177 g   C. 144 g   [✓ D.] 278 g

5. If 0.60 moles of sodium hydroxide, NaOH, are dissolved in 300 cm^3 of total water solution, the molar concentration of the solution is:

[✓ A.] 2.0 M   B. 0.60 M   C. 180 M   D. 1.8 M

Chemical Bonding

Here you will introduce the periodic relationship of the elements. This relationship becomes apparent through an investigation of ionization energies and through noting simple physical and chemical properties that the elements display. At this time, you need not deal extensively with the *Periodic Table of the Elements*. The periodic table is treated fully in *Diversity and Periodicity: An Inorganic Chemistry Module.*

An important idea developed here is that the number of electrons in the valence shell determines the chemical characteristics shown by the various chemical families. The observed stability of noble gases is related to the octet of electrons in their valence shells. This provides a foundation for dealing with bonding according to the "octet rule."

In discussing the photo of salt crystals on page 75, you may wish to refer interested students to *Diversity and Periodicity: An Inorganic Chemistry Module* and to *Communities of Molecules: A Physical Chemistry Module.* More discussion and illustrations of the structure of salt are presented in these two modules. Some students might enjoy borrowing a microscope from another science classroom (such as biology) and actually looking at table salt. Remind them that this photograph was taken with the aid of a scanning electron microscope, so what they observe will look noticeably different.

A-38 ELECTRONIC RIP-OFF;
A-39 ELECTRON-DOT STRUCTURES

The CHEM Study film *Ionization Energy* provides a good introduction to section *A-38 Electronic Rip-off.* This film is not essential, but it does provide perspective concerning how actual ionization energy values are obtained in the laboratory. The film also introduces the element-by-element trends that are represented in the chart on page 76, *Relative Ionization Energies for First 20 Elements.*

The CHEM Study film *Chemical Families* also provides an excellent introduction to family relationships among the elements. This film is also recommended for use with *Diversity and Periodicity: An Inorganic Chemistry Module.* You may wish to show the film at this time and repeat it later if you teach inorganic chemistry.

After discussing the photographs on page 77, some interested students might research the noble gases to find out more about the uses that these gases serve in their everyday lives. In each case, why is the noble gas so useful? *Diversity and Periodicity: An Inorganic Chemistry Module* and *Communities of Molecules: A Physical Chemistry Module* also discuss this topic.

The conclusion of section *A-38 Electronic Rip-off* suggests a class discussion on energy levels and on the capacity of electron shells. Note that this concluding reference serves as an introduction to section *A-39 Electron-Dot Structures.* Admittedly, we do not offer full experimental support for the details of the electronic arrangements described in these two sections. Instead, we are presenting the major features of a useful model—a model of atomic structure based on energy levels and stable octets of electrons.

The model will be applied to the study of bonding in specific molecules. The model's utility will become apparent as we are able to account for why certain atoms combine to form stable molecules (H_2, NH_3, Cl_2, etc.). Thus, we accept the model because it is useful. This is a valid test for any scientific theory or model.

The IAC approach to bonding avoids the use of s-p-d-f configurations, related spectrographic notation, orbital filling rules, promotion, and hybridization. Remember, a prime objective of this introductory module is to stimulate interest in chemistry and to present the necessary fundamentals that enable students to proceed with the study of other modules in the IAC program. Teaching the details of a quantum mechanical model for atomic structure is not necessary or even advisable in view of such objectives.

The electron-dot structures for the period 3 elements (the answer to the student module question at the top of page 79) are:

A-40 IONIC BONDING: GIVE AND TAKE

This presentation of ionic bonding and the gain and loss of electrons introduces the terms *oxidation* and *reduction* in a natural way (see text, page 80). Redox reactions will be encountered frequently in other IAC modules. Formal oxidation numbers are not introduced, since they are not needed here. Our examples are of simple structures, based on elements such as sodium, magnesium, and chlorine. Students will generally enjoy doing electron-dot structures and will gain comprehension of bonding from them.

Display any ionic packing models you might have available (e.g., NaCl) to illustrate that no simple NaCl "molecule" can be identified. Even though stable octets are achieved through the formation of ions, dot structures are more easily applied to molecular, covalent structures than to the "NaCl" type of ionic solid.

Some evidence for ions can be provided by doing a traditional electrical conductivity demonstration. Test distilled water (note that a one-quarter-watt neon glower will actually light), crystalline NaCl, and finally NaCl in water. It would also be worthwhile to fuse (melt) a typical ionic solid to suggest that ions are present even before the salt is dissolved in water. Reference is made to the melting of an ionic salt later, at the start of section *A-45 Polar Explorations*. You can refer back to this demonstration at that time.

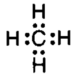
A-41 COVALENT BONDING: SHARE A PAIR

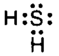
Despite their obvious differences, ionically bonded and covalently bonded substances both reach stability by the attainment of stable octets of valence electrons. This point is highlighted at the end of the section, where chlorine is used to illustrate that some elements can be involved in either electron transfer or electron sharing, depending on the type of element they react with. Some students may wonder why H_2O and NH_3 could not be ionic materials, formed by gain and loss of electrons (e.g., $H_2^{2+}O^{2-}$). The answer is based on experimental results, where H_2O and NH_3 form nonionic solids.

Many students will be familiar with the representation of a chemical bond by a dash (—) that connects two atoms. This is an opportunity for them to see what the dash actually represents: a pair of shared electrons that form a covalent bond. Dash structures are particularly useful for showing the bonding in more involved molecules. *Form and Function: An Organic Chemistry Module* and *Molecules in Living Systems: A Biochemistry Module* both make extensive use of this simplified method of showing covalent bonds.

One classic limitation in the "octet" model for bonding is that it implies that O_2 contains a double bond. While this picture is consistent with electron-dot rules, it fails to account for evidence that O_2 molecules actually contain unpaired electrons. Other bonding theories (molecular orbital theory, for example) deal more effectively with these complexities, but are not suitable "teaching" models for novice chemistry students.

Here are the dot structures students are asked to construct on page 82:

1. CH_4 
$\begin{array}{c}\mathrm{H}\\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}:\mathrm{H}\\ \mathrm{H}\end{array}$

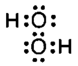
2. H_2S 
$\begin{array}{c}\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{S}}}:\\ \mathrm{H}\end{array}$

3. OH^- $[:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\mathrm{H}]^-$

4. H_2O_2 $\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\mathrm{H}$

5. HCN $\mathrm{H}:\mathrm{C}:::\mathrm{N}:$

Accept any dot structures that satisfy the octet rule. Students may note that in some cases the atoms can be arranged in different ways. Thus, H_2O_2 can be considered to be


$\begin{array}{c}\mathrm{H}:\ddot{\mathrm{O}}:\\ :\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\mathrm{H}\end{array}$

or


$\begin{array}{c}\mathrm{H}:\ddot{\mathrm{O}}:\\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\end{array}$

At this point, it is necessary only to observe that dot structures and the octet rule provide no clue concerning which structure, if any, is preferred. Miniexperiment *A-43 Constructing Models* is based on just this kind of question, as molecular shapes are first considered.

ANSWERS TO QUESTIONS

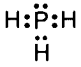
(Student module page 83)

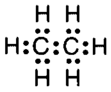
1. (a) Rb•; (b) $\dot{\mathrm{C}}\mathrm{a}\cdot$; (c) $:\underset{\cdot}{\dot{\mathrm{A}}}\mathrm{s}\cdot$; (d) $:\underset{\cdot\cdot}{\ddot{\mathrm{X}}}\mathrm{e}:$; (e) $:\underset{\cdot\cdot}{\ddot{\mathrm{B}}}\mathrm{r}\cdot$

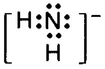
2. (a) Sr^+; (b) $:\underset{\cdot\cdot}{\ddot{\mathrm{B}}}\mathrm{r}:^-$; (c) Fr^+; (d) $:\underset{\cdot\cdot}{\ddot{\mathrm{P}}}:^{3-}$; (e) Al^{3+}

3. (a) $\dot{\mathrm{C}}\mathrm{a}\cdot + :\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}: \longrightarrow \mathrm{Ca}^{2+}\ 2[:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}:]^-$
   (b) $2\ \cdot\dot{\mathrm{A}}\mathrm{l}\cdot + 3\ :\ddot{\mathrm{O}}::\ddot{\mathrm{O}}: \longrightarrow 2\mathrm{Al}^{3+}\ 3[:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:]^{2-}$

4. (a) $\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{B}}}\mathrm{r}:$ (d) $[\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:]^-$

   (b) 
   $\begin{array}{c}\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{P}}}:\mathrm{H}\\ \mathrm{H}\end{array}$

   (e) 
   $\begin{array}{c}\mathrm{H}\ \ \mathrm{H}\\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}:\mathrm{H}\\ \mathrm{H}\ \ \mathrm{H}\end{array}$

   (c) 
   $\left[\begin{array}{c}\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{N}}}:\\ \mathrm{H}\end{array}\right]^-$

5. S^{2-} should have the largest diameter, since it has the lowest positive charge in its nucleus (+16). The electron clouds will thus not be as strongly attracted to the nucleus, producing a larger effective diameter for the ion. Conversely, Ca^{2+} should have the smallest diameter, with the highest nuclear charge (+20).

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Select the element from the following list that has the closest chemical resemblance to strontium. (Use the periodic table for help.)

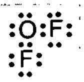
   A. Rubidium B. Yttrium C. Potassium D. Calcium

2. The number of valence electrons in an atom of bromine is:

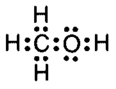
   A. 8 B. 4 C. 6 D. 7

3. Devise electron-dot structures for each of the following:

   A. Oxygen difluoride, OF_2

   
   $\begin{array}{l}:\ddot{\mathrm{O}}:\underset{\cdot\cdot}{\ddot{\mathrm{F}}}:\\ :\underset{\cdot\cdot}{\ddot{\mathrm{F}}}:\end{array}$

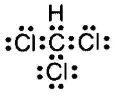
   B. Methyl alcohol, CH_3OH

   
   $\begin{array}{l}\ \ \mathrm{H}\\ \mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\mathrm{H}\\ \ \ \mathrm{H}\end{array}$

   C. Lithium iodide, LiI

   $[\mathrm{Li}]^+[:\underset{\cdot\cdot}{\ddot{\mathrm{I}}}:]^-$

   D. Chloroform, $CHCl_3$ (the atoms of Cl are not bonded to each other in this molecule)

   
   $\begin{array}{c}\mathrm{H}\\ :\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}:\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}:\\ :\underset{\cdot\cdot}{\ddot{\mathrm{C}}}\mathrm{l}:\end{array}$

Shapes of Molecules

This concluding portion of the module represents an application of the bonding concepts already introduced. Students are exposed to the idea that molecules have a geometry. This serves as a reminder that the molecular world is a three-dimensional one; it is not just a collection of flat symbols as pictured on textbook paper.

A-42 WHAT'S THE ANGLE?

The electron-pair repulsion theory introduced in this section is relatively new to high-school chemistry instruction. It should be apparent, however, that the theory generates a simple, remarkably reliable way of predicting molecular shapes. The fundamental approach also works for more complex structures, as students will learn when they study *Diversity and Periodicity: An Inorganic Chemistry Module.* The electron-pair repulsion approach is also called the Gillespie-Nyholm approach to molecular shapes, or the valence shell electron-pair repulsion (VSEPR) model.

The usual notions of electron promotion, hybridization, and related orbital-model concepts are not needed here and would substantially complicate the conceptual simplicity of the electron-pair repulsion model.

MINIEXPERIMENT
A-43 CONSTRUCTING MODELS

The purpose of this miniexperiment is to illustrate the positions assumed by four electron pairs arranged about a central atom, as modeled by Styrofoam-ball "atoms" and toothpick "electron pairs." The shape of an H_2O molecule is then predicted from this model.

Concepts

- Mutual repulsion of valence electron pairs forces them to arrange themselves as far as possible from each other in three-dimensional space around the atom.
- Such an arrangement of four electron pairs produces a characteristic (tetrahedral) shape.
- The shape of a molecule is defined by straight lines connecting the bonded atoms.

Objectives

- Construct a model for the positions of four electron pairs located about a central atom in three-dimensional space.
- Construct a model for a water molecule and estimate the angle formed by its bonds.

Estimated Time Half-period, including prelab discussion

Student Grouping Individuals

Materials

30 Styrofoam balls, 25–75-mm diameter (porous surface)
60 Styrofoam balls, 12–25-mm diameter (porous surface)
toothpicks, 1 box
Note: Marshmallows, gum drops, or other porous, spherical materials can be substituted for the plastic balls.

Advance Preparation None

Prelab Discussion Review the two suggested dot structures for H_2O on page 85 of the student module. Pose the problem that will be considered in this activity: What is the position of four electron pairs arranged about a central atom? Discuss. Call upon your students to make predictions.

Laboratory Tips None. If you use gum drops or marshmallows, be careful—"atoms" may not be conserved!

Postlab Discussion Review the structures that the students assemble. You may wish to introduce the term *tetrahedral*, depending on your own taste. The postlab discussion leads directly into section *A-44 The Shape We're In*. Keep the toothpicks and Styrofoam balls handy, since you may want to have students construct models of the molecules that are highlighted in section *A-44*.

A-44 THE SHAPE WE'RE IN

Be sure your students understand the distinction between bonding pairs of electrons and nonbonding pairs of electrons, as shown in the table on page 86 of the student module. This section could be assigned as a desk exercise or as a homework task. Suggest to your students that they construct models of hydroxide, ammonia, and methane from the materials of miniexperiment *A-43 Constructing Models*. This is also an appropriate time to display and use models available from scientific-supply houses. Perhaps you have access to ball-and-stick models or to snap-on space-filling models.

The photograph in the margin of page 86 is a model illustrating the shape of a molecule of DNA. This is discussed in more detail in *Molecules in Living Systems: A Biochemistry Module.*

A-45 POLAR EXPLORATIONS

An attention getting (hair-raising?) introduction to this section is found in a simple hair-combing demonstration (assuming that room humidity is not too high).

Demonstration Turn on a water tap to produce a fine, smooth stream of water visible to the students. Have a student comb his or her hair rapidly with a plastic comb. Then instruct the student to bring the comb near the stream of water. Observation: The water stream bends (at least a little!) toward the comb.

If possible, have the student vigorously comb a lock of long hair. Quickly place the lock of hair near the water stream. Observation: The water stream bends (at least a little!) toward the lock of hair. Finally, have the student demonstrate that the plastic comb attracts the just-combed lock of hair.

Invite students to discuss possible interpretations of the preceding demonstration. Since the comb and hair attract each other, they must possess opposite charges. Yet, since each alone attracts the water stream, water must be attracted by both positive and negative charges! Thus, one must conclude that water molecules have both negative and positive character.

This section suggests a "pay-off" for our concern about molecular shapes: Molecular shapes and the distribution of electrons in chemical bonds help to determine the physical and chemical properties of many substances. We focus our attention on water here. The importance of molecular shape is highlighted in other ways in *Molecules in Living Systems: A Biochemistry Module.*

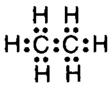
For more discussion of hydrogen bonding, interested students can refer to *Form and Function: An Organic Chemistry Module* and *Diversity and Periodicity: An Inorganic Chemistry Module.*

ANSWERS TO QUESTIONS

(Student module page 89)

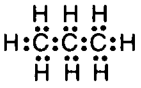
1. Structures (b), (c), and (e) are polar. The sketched shapes should roughly follow these guidelines: (a) tetrahedral; (b) bent; (c) tetrahedral, with an H at one point and a Cl at each of the remaining three points; (d) bent; (e) a "zig-zag" shape, best seen by constructing a model with toothpicks and balls, or by using conventional ball-and-stick models.

2. C_2H_6



$$\begin{array}{c} \mathrm{H\ \ H} \\ \mathrm{H{:}\ddot{\underset{..}{C}}{:}\ddot{\underset{..}{C}}{:}H} \\ \mathrm{H\ \ H} \end{array}$$

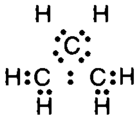
C_3H_8



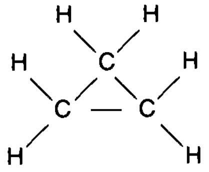
$$\begin{array}{c} \mathrm{H\ \ H\ \ H} \\ \mathrm{H{:}\ddot{\underset{..}{C}}{:}\ddot{\underset{..}{C}}{:}\ddot{\underset{..}{C}}{:}H} \\ \mathrm{H\ \ H\ \ H} \end{array}$$

(The C_2H_6 molecule is linear, with the two clusters of three H atoms angled away from the center of molecule at each end of the structure. C_3H_8 assumes a zig-zag shape due to the angle defined by the three C atoms. Ball-and-stick models will clarify the geometry for each model.)

C_3H_6



or

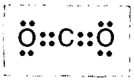


C_3H_6 has the shape of a flat triangle, with hydrogens above and below the plane of the triangle.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding section. The correct answer to each question is indicated by shading.

1. Devise an electron-dot structure for carbon dioxide, CO_2. (Hint: The molecule contains two double bonds.) Predict the shape of a carbon dioxide molecule.



$\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}::C::\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}$

Linear shape

2. Pure hydrogen and pure oxygen are both gases at room temperature, as you already know. Yet water, a simple compound of hydrogen and oxygen, is a *liquid* at room temperature and a solid in northern U.S. winter temperatures. Although common sense might suggest that a compound of two gases would also be a gas, this is not true for water. Explain the "strange" behavior of water!

The extra attractive force of hydrogen bonds is the primary explanation.

Ending The Beginning

You may wish to review with your students the list of topics they compiled at the beginning of the module when they were looking through newspapers and periodicals for headlines and articles on present-day chemistry. Help them make a list of general topic areas of concern to the public today. Compare this with the list of topics mentioned in the student module on page 90.

The photograph on page 90 illustrates a "new" frontier in chemistry—the area beneath the oceans. It is, and will be, more important to us in terms of available natural resources and the chemistry of underwater animal life. Many articles are being written on this topic. Interested students might wish to find out more about this area of chemistry (and also many other areas of science).

Ask your students to volunteer their own unanswered questions, similar to the ones found on page 91. You may wish to make a list of these and help them pursue some of the answers as they continue their study of chemistry.

Review with your students the range of skills and concepts that they have been introduced to in this module, thus setting the stage for the next module you have selected for your students. Meanwhile, we hope that you and your students have enjoyed using *Reactions and Reason: An Introductory Chemistry Module.*

Appendix Material In Student Module

Appendices II, III, and IV in the *Reactions and Reason* student module represent material that your students may be directed to complete if you desire further support for the topics of the metric system, problem solving with dimensional analysis, or significant figures and rounding off.

The material is presented in self-contained fashion, except for the answers to problems in Appendix III (page 96), which are presented below. We hope you will find these appendices useful in extending student familiarity and skill with these basic topics.

1. $6.25\,\cancel{\text{h}}\left(\frac{84.0\text{ km}}{1\,\cancel{\text{h}}}\right) = 525\text{ km}$

2. $3\,\cancel{\text{years}}\left(\frac{365\,\cancel{\text{days}}}{1\,\cancel{\text{year}}}\right)\left(\frac{24\text{ hours}}{1\,\cancel{\text{day}}}\right) = 26\,280\text{ hours}$

3. $3\,\cancel{\text{vol}}\left(\frac{125\,\cancel{\text{pages}}}{1\,\cancel{\text{vol}}}\right)\left(\frac{1\text{ min}}{12\,\cancel{\text{pages}}}\right) = 31.25\text{ min (31 min)}$

4. (a) $122\,\cancel{\text{g}}\left(\frac{1\text{ mg}}{10^{-3}\,\cancel{\text{g}}}\right) = 122 \times 10^{3}\text{ mg}$

   $= 12\,200\text{ mg} = (1.22 \times 10^{4}\text{ mg})$

   (b) $122\,\cancel{\text{g}}\left(\frac{1\text{ kg}}{10^{3}\,\cancel{\text{g}}}\right) = 122 \times 10^{-3}\text{ kg} = 0.122\text{ kg}$

5. $8.0\,\cancel{\text{hours}}\left(\frac{60\,\cancel{\text{minutes}}}{1\,\cancel{\text{hour}}}\right)\left(\frac{3.2\,\cancel{\text{milliliters}}}{1\,\cancel{\text{minute}}}\right)\left(\frac{1\text{ liter}}{1000\,\cancel{\text{milliliters}}}\right)$

   $= 1.536\text{ liters} = 1.5\text{ liters}$

6. $0.405\,\cancel{\text{pow}}\left(\frac{5\,\cancel{\text{ping}}}{3\,\cancel{\text{pow}}}\right)\left(\frac{12\,\cancel{\text{zoom}}}{1\,\cancel{\text{ping}}}\right)\left(\frac{8\text{ zing}}{1\,\cancel{\text{zoom}}}\right) = 64.8\text{ zing}$

7. (a) 0.15 m (given!); (b) 1.5 m (longest); (c) 0.015 m; (d) 0.0015 m (shortest)

Appendix

Safety

SAFETY IN THE LABORATORY

Proper conduct in a chemistry laboratory is really an extension of safety procedures normally followed each day around your home and in the outside world. Exercising care in a laboratory demands the same caution you apply to driving a car, riding a motorbike or bicycle, or participating in a sport. Athletes consider safety measures a part of playing the game. For example, football players willingly spend a great deal of time putting on equipment such as helmets, hip pads, and shoulder pads to protect themselves from potential injury.

Chemists must also be properly dressed. To protect themselves in the laboratory, they commonly wear a lab apron or a coat and protective glasses. Throughout this course you will use similar items. Hopefully their use will become second nature to you, much as it becomes second nature for a baseball catcher to put on a chest protector and mask before stepping behind home plate.

As you read through a written experimental procedure, you will notice that specific hazards and precautions are called to your attention. Be prepared to discuss these hazards with your teacher and with your fellow students. Always read the entire experimental procedure thoroughly before starting any laboratory work.

A list of general laboratory safety procedures follows. It is not intended that you memorize these safety procedures but rather that you *use* them regularly when performing experiments. You may notice that this list is by no means complete. Your teacher may wish to add safety guidelines that are relevant to your specific classroom situation. It would be impossible to anticipate every hazardous situation that might arise in the chemistry laboratory. However, if you are familiar with these general laboratory safety procedures and if you use common sense, you will be able to handle potentially hazardous situations intelligently and safely. Treat all chemicals with respect, not fear.

GENERAL SAFETY GUIDELINES

1. Work in the laboratory only when the teacher is present or when you have been given permission to do so. In case of accident, notify your teacher immediately.
2. Before starting any laboratory exercise, be sure that the laboratory bench is clean.
3. Put on a laboratory coat or apron and protective glasses or goggles before beginning an experiment.
4. Tie back loose hair to prevent the possibility of its contacting any Bunsen burner flames.
5. Open sandals or bare feet are not permitted in the laboratory. The dangers of broken glass and corrosive liquid spills are always present in a laboratory.
6. Fire is a special hazard in the laboratory because many chemicals are flammable. Learn how to use the fire blanket, fire extinguisher, and shower (if your laboratory has one).
7. For minor skin burns, immediately immerse the burned area in cold water for several minutes. Then consult your teacher for further instructions on possible additional treatment.
8. In case of a chemical splash on your skin, immediately rinse the area with cold water for at least one minute. Consult your teacher for further action.
9. If any liquid material splashes into your eye, wash the eye immediately with water from an eyewash bottle or eyewash fountain.
10. Never look directly down into a test tube—view the contents of the tube from the side. (Why?)
11. Never smell a material by placing your nose directly at the mouth of the tube or flask. Instead, with your hand, "fan" some of the vapor from the container toward your nose. Inhale cautiously.
12. Never taste any material in the laboratory.
13. Never add water to concentrated acid solutions. The heat generated may cause spattering. Instead, as you stir, add the acid slowly to the water or dilute solution.
14. Read the label on a chemical bottle at least *twice* before removing a sample. H_2O_2 is not the same as H_2O.
15. Follow your teacher's instructions or laboratory procedure when disposing of used chemicals.

This symbol represents three of the common hazards in a chemistry laboratory—flame, fumes, and explosion. It will appear with certain experiments in this module to alert you to special precautions in addition to those discussed in this Appendix.

Metric Units

PHYSICAL QUANTITY	SI BASE OR DERIVED UNIT		OTHER UNITS	
	NAME	SYMBOL AND DEFINITION	NAME	SYMBOL AND DEFINITION
length	meter*	m	kilometer	$1\ \text{km} = 10^{3}\ \text{m}$
			centimeter	$1\ \text{cm} = 10^{-2}\ \text{m}$
			nanometer	$1\ \text{nm} = 10^{-9}\ \text{m} = 10^{-7}\ \text{cm}$
area	square meter	m^2	square centimeter	$1\ \text{cm}^2 = 10^{-4}\ \text{m}^2$
volume	cubic meter	m^3	cubic centimeter	$1\ \text{cm}^3 = 10^{-6}\ \text{m}^3$
			liter	$1\ \text{l} = 10^{3}\ \text{cm}^3$
mass	kilogram*	kg	gram	$1\ \text{g} = 10^{-3}\ \text{kg}$
time	second*	s		
amount of substance	mole*	mol		
concentration	moles per cubic meter	mol/m^3	moles per liter	$1\ \text{mol/l} = 10^{3}\ \text{mol/m}^3$
			molar concentration (molarity)	$1\ \text{M} = \text{mol/l}$
Celsius temperature			degree Celsius	°C
thermodynamic temperature	kelvin*	K		
force	newton	$\text{N} = \text{kg} \cdot \text{m/s}^2$		
pressure	pascal	$\text{Pa} = \text{N/m}^2 = \text{kg/(m} \cdot \text{s}^2)$	centimeter of mercury	$1\ \text{cm Hg} = 1.333 \times 10^{3}\ \text{Pa}$
			atmosphere	$1\ \text{atm} = 1.013 \times 10^{5}\ \text{Pa}$ $1\ \text{atm} = 76.0\ \text{cm Hg}$
energy	joule	$\text{J} = \text{N} \cdot \text{m} = \text{kg} \cdot \text{m}^2/\text{s}^2$	calorie	$1\ \text{cal} = 4.184\ \text{J}$

*SI base unit, exactly defined in terms of certain physical measurements.

Selected Readings and Films for *Reactions and Reason*

BOOKS

Patterson, Elizabeth C. *John Dalton and the Atomic Theory.* Science Study Series. New York: Doubleday & Co., Inc., 1970, 360 pp. Paperback.
The "father of the atomic theory" studied in terms of the social, economic, and scientific environments of his time.

Pauling, Linus, and Hayward, Roger. *The Architecture of Molecules.* San Francisco: W. H. Freeman & Co., Publishers, 1970. Paperback.
Excellent graphics and enlightening science—a delight for both eye and mind.

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Briggs, Bill. "Puns on the Periodic Table." *Chemistry*, April 1976, p. 18.

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Gillespie, R. J. "The Electron-Pair Repulsion Model for Molecular Geometry." *Journal of Chemical Education*, January 1970, pp. 18–23.

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Skokesalvi-Nagy, Zoltan. "How and Why of Chemical Symbols." *Chemistry*, February 1967, pp. 21–23.

Strong, Laurence E. "Balancing Chemical Equations." *Chemistry*, January 1974, pp. 13–15.

Webb, Valerie J. "Hydrogen Bond, Special Agent." *Chemistry*, June 1968, pp. 16–20.

AUDIOVISUAL MATERIALS

FILMS

Energy and Matter. National Film Board of Canada. Color, 9 minutes.

These titles were produced by CHEM Study Films and are distributed by Modern Learning Aids Division, Ward's Natural Science Establishment, Rochester, New York:

Chemical Families. Color, 22 minutes. Provides a chance to "see" more than seventy elements and to observe many of their common reactions.

Ionization Energy. Color, 22 minutes. Demonstrates methods for determining the ionization energy of elements. Ionization energy trends are also examined.

Molecular Motions. Color, 13 minutes. Illustrates through animation and dynamic models how types of molecular motion account for many properties of matter.

Shapes and Polarities of Molecules. Color, 18 minutes. Molecular dipoles—how they are detected and how they influence solubility, conductivity, and chemical reactivity.

This group of films was produced by McGraw-Hill Films. The first is available from the producer; the others may be available from an audiovisual center.

A Look at Chemical Change. Color, 15 minutes.
Kinetic Molecular Theory. Color, 9 minutes.
The Structure of Atoms. Color, 13 minutes.
Wonder of Chemistry. 2nd ed. Color, 10 minutes.

FILMSTRIPS

Definite Composition. Eye Gate House.

Electron Arrangement and Chemical Bonds. Encyclopaedia Britannica Educational Corporation.

Heat and Temperature—Molecular Energy. Denoyer-Geppert.

Ionic and Covalent Bonds. Encyclopaedia Britannica Educational Corporation.

Modern Measure: The SI Metric System. Prentice-Hall Media, Inc. A two-part program consisting of *Overview of Metric Measurement* (three filmstrips) and *SI Metrics in Science* (one filmstrip). Available separately.

The Mole Concept. Denoyer-Geppert.

The Mole Concept. Encyclopaedia Britannica Educational Corporation.

The Simplest Formula of a Compound. Encyclopaedia Britannica Educational Corporation.

SOURCES FOR AUDIOVISUAL MATERIALS CITED

Denoyer-Geppert Audiovisuals
5235 Ravenswood
Chicago, IL 60640

Encyclopaedia Britannica Educational Corporation
425 N. Michigan Avenue
Chicago, IL 60611

Eye Gate House
146-01 Archer Avenue
Jamaica, NY 11435

McGraw-Hill Films
1221 Avenue of the Americas
New York, NY 10020

Modern Learning Aids Division
Ward's Natural Science Establishment
P.O. 1712
Rochester, NY 14603

National Film Board of Canada
1251 Avenue of the Americas
New York, NY 10020

Prentice-Hall Media, Inc.
150 White Plains Road
Tarrytown, NY 10591

Reactions and Reason Module Tests

Two module tests follow, one to test knowledge-centered objectives and the other to test skill-centered objectives. If you choose to use either or both of these module tests as they are presented here, duplicate copies for your students. Or, you may wish to select some questions from these tests that you feel apply to *your* introductory chemistry course and add questions of your own. Either way, make sure that the test you give reflects your emphasis on the chemistry you and your students experienced in this introductory module.

For the skill-centered tests, you will need to set up several laboratory stations containing materials for your students to examine or work with. You may wish to incorporate additional test items to round out the types of skills you and your students have practiced. (Answers to the test questions in this section are provided.)

If you wish to use a standard-type answer sheet with these tests, we have provided one for your convenience. It follows the Skill-Centered Module Test in the teacher's guide. Duplicate enough copies for each of your students to use, or revise the format to fit your own testing situation.

ANSWERS FOR REACTIONS AND REASON KNOWLEDGE-CENTERED MODULE TEST

1. A; **2.** D; **3.** B; **4.** A; **5.** D; **6.** C; **7.** C; **8.** D; **9.** A; **10.** C; **11.** A; **12.** C; **13.** C; **14.** D; **15.** C; **16.** D; **17.** D; **18.** C; **19.** D; **20.** D; **21.** D; **22.** B; **23.** D; **24.** B; **25.** C; **26.** B; **27.** A; **28.** B; **29.** A; **30.** B

REACTIONS AND REASON
Knowledge-Centered Module Test

1. The formula for sodium oxide is

A. Na_2O B. NaO C. Na_2O_2 D. NaO_2

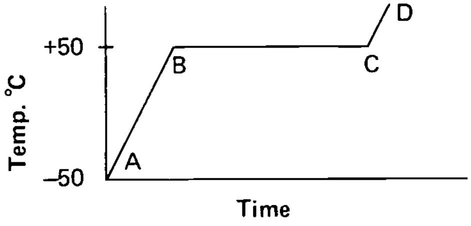
2. The equation for the reaction between zinc and sulfur is: $Zn + S \longrightarrow ZnS$. The expression which is consistent with this equation is

A. 1 mole Zn + 1 mole S ⟶ 2 moles ZnS
B. 20 atoms Zn + 20 atoms S ⟶ 40 molecules ZnS
C. 1 gram Zn + 1 gram S ⟶ 2 grams ZnS
D. 65.4 grams Zn + 32.1 grams S ⟶ 97.5 grams ZnS

3. Which statement does *not* describe a useful theory?

A. The theory can be used to predict new situations.
B. The theory can usually be proven true.
C. The theory should not contradict known facts.
D. The theory is subject to change if it is contradicted by new facts.

4. This graph was obtained by plotting data for the heating curve of a liquid.



The liquid's boiling point is represented

A. between B and C C. below A
B. at point D D. between A and B

5. When Noah was told to build an ark, the dimensions were specified as 80×40 cubits. A cubit was approximately the distance between an average adult's elbow and wrist. Today the dimensions of Noah's ark in metric units would be

A. 24.4×12.2 km C. 24.4×12.2 g
B. 24.4×12.2 cm D. 24.4×12.2 m

6. The correct electron-dot structure for $CaCl_2$ is

A. $Ca{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Cl}}{:}Ca$ C. $Ca^{2+} + 2[{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Cl}}{:}^{-}]$
B. $2\ Ca^{+} + {:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Cl}}{:}^{-}$ D. $Ca^{+} + 2[{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Cl}}{:}^{-}]$

7. When most atoms are bonded together they try to obtain electron populations containing

A. six electrons in their outermost shells.
B. two electrons in their outermost shells.
C. eight electrons in their outermost shells.
D. seven electrons in their outermost shells.

8. The best name for $CuSO_4$ is

A. copper(I) sulfate. C. cuprous sulfate.
B. copper sulfate. D. copper(II) sulfate.

9. A process exhibiting a physical change is

A. the liquefaction of methane gas.
B. the reaction between Cu and S.
C. the formation of H_2O from H_2 and O_2.
D. the ionization of Na.

10. A student mixed two liquid substances together. Which statement would *not* be accepted as evidence that a chemical reaction has occurred?

A. A precipitate has formed.
B. A gas has been given off.
C. A boundary has formed between the two liquids.
D. A temperature change has been observed.

11. Ionization is represented by

A. $Li \longrightarrow Li^{+} + e^{-}$ C. $Cl^{+} + Cl^{-} \longrightarrow Cl_2$
B. $K^{+} + Cl^{-} \longrightarrow KCl$ D. $Cl + Cl \longrightarrow Cl_2$

12. The HCl molecule has $H{:}\underset{\cdot\cdot}{\overset{\cdot\cdot}{Cl}}{:}$ as its dot structure, and it

A. contains 1 pair of non-bonding electrons.
B. contains 2 pairs of bonding electrons.
C. contains 3 pairs of non-bonding electrons.
D. contains 4 pairs of bonding electrons.

13. The symbols $^{16}_{8}O$ and $^{18}_{8}O$ indicate that these two types of oxygen atoms

A. contain different numbers of protons.
B. contain different numbers of electrons.
C. contain different numbers of neutrons.
D. have the same atomic mass.

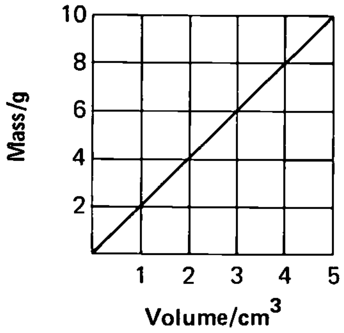
14. Which term describes the shape of the CCl_4 molecule?

A. linear
C. angular
B. tripod-shaped
D. tetrahedral

15. Two moles of $(NH_4)_2S$ have a mass of

A. 76 grams
C. 136 grams
B. 100 grams
D. $2(6.02 \times 10^{23})$ grams

16. The graph below was obtained by plotting the mass of a material versus the volume of that same material.



The material's density is

A. 0.500 g/cm³
C. 1.50 g/cm³
B. 1.00 g/cm³
D. 2.00 g/cm³

17. Forty grams of NaOH are dissolved in water and diluted to 500 cm³. The solution's concentration is

A. 0.002 M B. 0.08 M C. 0.5 M D. 2 M

18. The total number of atoms represented by the formula $Ca(NO_3)_2$ is

A. five B. eight C. nine D. ten

19. In a compound "XS" formed between element X and sulfur it was determined that the mass ratio X/S is 1.74. Using the molar mass of sulfur as 32.0 g/mol, the molar mass of element X is

A. 0.0312 g/mol
C. 32.0 g/mol
B. 18.4 g/mol
D. 55.7 g/mol

20. The Kinetic Molecular Theory implies that

A. molecules in a liquid move faster than those of a gas.
B. atoms of a solid have no definite arrangement.
C. atoms form diatomic molecules at high temperatures.
D. molecules move faster when the temperature increases.

21. A student mixed two colorless liquids together producing a warm, yellow, bubbling solution as well as a white solid. An interpretation of the observations made above is that

A. there was a color change produced by the reaction.
B. a precipitate was produced by the reaction.
C. heat was produced by the reaction.
D. NH_3 gas was produced by the reaction.

22. A student was asked to identify an unknown compound from the six listed below. The density, boiling point, and melting point of the compound were determined in the laboratory as:

Density: 0.85 g/cm³; Boiling Point: 79°C; Melting Point: 4°C

Compound	*Melting Point (°C)*	*Boiling Point (°C)*	*Density (g/cm³)*
Acetone	−95	56	0.80
Allyl chloride	−136	45	0.90
Benzene	+5	80	0.90
n-Butyl chloride	−89	118	0.80
Ethyl alcohol	−117	78	0.80
Isopropyl alcohol	−86	100	0.80

The student's unknown was

A. Allyl chloride
C. Ethyl alcohol
B. Benzene
D. Acetone

23. The mass number of $^{27}_{13}Al$ is

A. 10 B. 13 C. 14 D. 27

24. A student was given a mixture containing the following four solid pure substances.

	Solubility in			
Substance	*Cold Water*	*Hot Water*	*Acetone*	*Sublimes*
A	V	V	I	No
B	I	V	I	No
C	I	I	V	No
D	I	I	I	Yes

I—insoluble
V—very soluble

A suitable method for separating this mixture into its four substances would be to

A. sublime the mixture, dissolve the remaining solid in hot water and filter, and dissolve the remaining solid in acetone.
B. dissolve the mixture in cold water and filter, dissolve the remaining solid in hot water and filter, and dissolve the remaining solid in acetone and filter.
C. dissolve the mixture in acetone and filter, dissolve the remaining solid in hot water and filter, and dissolve the remaining solid in cold water and filter.
D. dissolve the mixture in hot water and filter, dissolve the remaining solid in acetone, and sublime the remaining solid.

25. The reaction between antimony and chlorine can be written as

$$\underline{\ ?\ }\ \mathrm{Sb} + \underline{\ ?\ }\ \mathrm{Cl_2} \longrightarrow \underline{\ ?\ }\ \mathrm{SbCl_3}$$

Identify the appropriate coefficients for this reaction in order of their appearance.

A. 1, 1, 1 B. 2, 1, 2 C. 2, 3, 2 D. 6, 3, 2

26. According to this equation, $S + O_2 \rightarrow SO_2$, 44.9 grams of sulfur produce

A. 64.2 grams of SO_2
B. 89.7 grams of SO_2
C. 100 grams of SO_2
D. 128 grams of SO_2

27. How many moles of CO_2 are there in 8.80 grams of CO_2?

A. 0.200
B. 0.333
C. 6.02×10^{23}
D. $8.80(6.02 \times 10^{23})$

28. When chemists separate mixtures or compounds into their component parts for investigation, the process being used is called

A. synthesis
B. analysis
C. reduction
D. neutralization

29. A basic idea of Dalton's Atomic Theory was that

A. each element is composed of atoms alike in size and mass.
B. atoms are composed of electrons, neutrons and protons.
C. atoms of the same element are chemically different.
D. atoms of all matter have equal mass.

30. It was determined that 50.0 grams of mixture of A and B contained 15.0 grams of A. The percentage of A in the sample is

A. 15.0% B. 30.0% C. 35.0% D. 70.0%

Reactions and Reason Skill-Centered Module Test

Using the skill-centered test items will require certain advance preparations on your part. The numerals in the following list indicate the items for which you will have to prepare special laboratory stations. Be sure to test each of the lab stations before allowing students to determine the answers to the skill-centered items. When students are ready to answer these questions, they should go to the numbered station and follow the directions that are given there and in the printed question item. When they finish with the materials at the station, instruct them to leave the materials in proper order for the next student.

1. Provide 2 test tubes numbered 1 and 2, with the 5 cm^3 level marked on each by a piece of masking tape. Solution X is 3 Molar HCl. Dilute 125 cm^3 of concentrated HCl to a volume of 500 cm^3. Solution A is 3 Molar NaOH. Dissolve 30 g NaOH in 250 cm^3 water. Solution B is 0.50 Molar $Pb(NO_3)_2$. Dissolve 42.5 g in 250 cm^3 water.

3. Supply each student with a piece of linear graph paper.

8. Set up and label the following equipment.

A. evaporating dish
B. 250-cm^3 beaker
C. 250-cm^3 Erlenmeyer flask
D. 25-cm^3 graduated cylinder

9. Provide 3 test tubes in a rack, each with a mark at the 2 cm^3 and 5 cm^3 levels. Provide these salts in beakers labeled A, B, C.

A. KNO_3
B. $NaNO_2$ or KNO_2 or any salt less soluble than A
C. NaCl or other salt less soluble than A

13. Place the *Physical Properties of Some Common Substances* table from the student module (page 25) at station for reference.

15. Provide each student with a piece of linear graph paper.

19. Rubber stoppers or corks make good unknowns. Mark a code number or letter with red crayon or other marker on each. Weigh the objects yourself before or after the exam. Check, balance, and zero all balances before beginning.

ANSWER KEY:

1a. C; **1b.** B; **2.** A; **3.** *; **4.** D; **5.** C; **6.** D; **7.** C; **8.** D; **9.** A; **10.** B; **11.** A; **12.** C; **13.** C; **14.** B; **15.** B; **16.** C; **17.** C; **18.** C; **19.** *

*Evaluate according to teacher standards.

REACTIONS AND REASON
Skill-Centered Module Test

Several questions in this section require you to make observations and perform chemical manipulations. The stations where you will do these operations will be indicated by your teacher. If the station you are going to is being used, continue with the test and go back later.

1. Go to station 1 where you will find two test tubes (1 and 2) in the test tube rack. The 5 cm^3 level is indicated on each by a ring. Add solution X to the level indicated in each tube using the beaker provided.

   Add an equal amount of solution A to tube 1. Record your observations on the back of your answer sheet.

   Add an equal amount of solution B to tube 2. Record your observations on the back of your answer sheet.

   RINSE OUT THE TEST TUBES. NOW ANSWER QUESTIONS (a) AND (b) BELOW

   (a) In test tube 1 you observed:

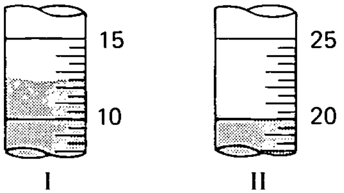
   A. no reaction C. evolution of heat
   B. change in color D. evolution of a gas

   (b) In test tube 2 you observed:

   A. no reaction C. evolution of heat
   B. change in color D. evolution of a gas

2. A graduated cylinder was used to determine the volume of an object by water displacement. Cylinder I shows the water level before addition of the object, and cylinder II shows the water level after addition of the object. The volume of the object is:

   A. 7.6 cm^3 B. 7.0 cm^3 C. 5.0 cm^3 D. 7.4 cm^3



3. Using a piece of graph paper, graph the data shown below.

Mass of Gas Dissolved (g)	*Temperature (°C)*
0.550	0
0.150	40
0.450	10
0.350	20
0.050	50

4. Using the graph you constructed in question 3, the mass of gas that would dissolve at 25°C is

   A. 0.250 g B. 0.325 g C. 0.275 g D. 0.300 g

5. From the graph completed in question 3 above, you would conclude that:

   A. the solubility of a gas increases with increasing temperature.
   B. the solubility of a gas stays the same with increasing temperature.
   C. the solubility of a gas decreases with increasing temperature.
   D. the solubility of a gas decreases with decreasing temperature.

6. A sample of $KClO_3$ was decomposed to yield KCl and O_2. From the following data determine the number of grams of O_2 produced.

   Mass of dish .... 36.48 g
   Mass of dish and sample .... 39.98 g
   Mass of dish and sample
   after removal of O_2 .... 37.92 g

   The mass of O_2 produced is:

   A. 3.50 g B. 1.36 g C. 1.44 g D. 2.06 g

7. Using the data from question 6 above, calculate the percent KCl in $KClO_3$. The percent KCl in $KClO_3$ is

   A. 69.9% B. 58.8% C. 41.1% D. 62.3%

8. Go to station 8 and examine the equipment provided. Which piece of equipment would be used in determining the density of a solid?

A. A B. B C. C D. D

9. Go to station 9 and test each of the three solids provided for their solubility in cold water. Fill each of the test tubes to the first mark with one of the salts. Then add water to each tube to the second mark. The solid with the greatest solubility in cold water is:

A. A B. B C. C D. B and C are equal

10. Using the data below, you would conclude that:

A. solids A and B are the same.
B. solids A and B are different.
C. no conclusion is possible from the data given.

Solid	Appearance	Solubility in Alcohol	Solubility in Water 100°C	Solubility in Water 0°C	Density g/cm³
A	white crystal	Insoluble	180 g/100 cm³	70 g/100 cm³	0.68
B	white crystal	Insoluble	220 g/100 cm³	72 g/100 cm³	0.67

11. The following data were obtained in determining the density of a water-insoluble material:

Mass of dish and sample	14.75 g
Mass of dish, empty	12.50 g
Water level before adding sample	16.85 cm³
Water level after adding sample	25.85 cm³

The density of the material is:

A. 0.250 g/cm³ C. 0.500 g/cm³
B. 4.00 g/cm³ D. 2.50 g/cm³

12. You are given an unknown compound that is believed to be one of four compounds: X, Y, Z or W. If you were only allowed to conduct one test for its identification, which of the following properties would you determine?

A. Density C. Solubility in 20°C water
B. Melting Point D. Boiling Point

Substance	Density (g/cm³)	Melting Point (°C)	Boiling Point (°C)	Solubility in Water (g/100 cm³) 20°C	100°C
X	1.65	80	325	20	360
Y	1.63	82	327	15	350
Z	1.60	80	330	8	365
W	1.58	76	325	10	340

13. You are given an unknown pure substance and your data table after many tests on the sample appears as follows:

Test	*Result*
Boiling point	81°C
Freezing point	5.6°C
Density	0.88 g/cm³
Solubility in water	Insoluble
Solubility in ethanol	Very soluble

Using the table below, your unknown is most likely

A. Oleic acid C. Benzene
B. Cyclohexane D. Chloroform

	Density (g/cm³)	Freezing Point (°C)	Boiling Point (°C)	Solubility Water	Ethanol
Benzene	0.879	5.5	80.8	I	V
Chloroform	1.498	−63.5	61.2	I	V
Cyclohexane	0.779	6.5	80.7	I	V
Oleic acid	0.895	16.3	286.0	I	V

I—insoluble
V—very soluble

14. An experiment was performed in which Fe was converted to FeO and then reconverted back to Fe. Using the data below, calculate the percent recovery of Fe.

Mass of dish plus Fe at start	50.6 g
Mass of dish	26.6 g
Mass of dish plus Fe at end	44.4 g

$$\% \text{ Recovery} = \frac{\text{Final Mass Fe}}{\text{Original Mass Fe}} \times 100$$

The percent recovery is:

A. 34.8% B. 74.2% C. 25.8% D. 87.7%

15. The solubility of a substance in water was found to be:

5 g/100 cm³ at 25°C
10 g/100 cm³ at 50°C
15 g/100 cm³ at 75°C

You would predict its solubility at 100°C to be:

A. 18 g/100 cm³ C. 22 g/100 cm³
B. 20 g/100 cm³ D. 16 g/100 cm³

16. While performing the recycling-of-copper experiment, some concentrated HCl accidentally spills on a student's arm. The student should *first*:

A. tell a lab partner to summon help.
B. neutralize the acid with a weak base such as $NaHCO_3$.
C. wash the arm with large amounts of water.
D. dry the arm and continue with the experiment until the student can go to the nurse for aid.

17. After making observations in the laboratory you discover your results do not agree with those of other members of the class. To resolve the problem you should:

A. have confidence in your work and report your results.
B. discuss the problem with others and reach a common answer.
C. repeat the observations.
D. change your results to match those of the other members of the class.

18. The largest source of error resulting in a low yield in the recycling-of-copper experiment would be:

A. not drying the sample at the end before weighing.
B. not removing all the excess zinc with acid.
C. not converting the CuO completely to $CuSO_4$ before adding zinc.
D. converting the Cu to CuO while drying the sample before weighing.

19. Go to station 19 and determine the mass of one of the objects. Record the object's identification number or letter and the mass you determine at the bottom of your answer sheet next to 19.

IAC TEST ANSWER SHEET

Test Type (check)

☐ KNOWLEDGE-CENTERED
☐ SKILL-CENTERED

NAME		SCORE
DATE	CLASS PERIOD	
TEACHER		

Module Test (check)

☐ INTRODUCTORY	☐ ORGANIC	☐ INORGANIC	☐ NUCLEAR
☐ PHYSICAL	☐ ENVIRONMENTAL	☐ BIOCHEMICAL	☐ COMPREHENSIVE

	A	B	C	D		A	B	C	D		A	B	C	D		A	B	C	D
1.	☐	☐	☐	☐	11.	☐	☐	☐	☐	21.	☐	☐	☐	☐	31.	☐	☐	☐	☐
2.	☐	☐	☐	☐	12.	☐	☐	☐	☐	22.	☐	☐	☐	☐	32.	☐	☐	☐	☐
3.	☐	☐	☐	☐	13.	☐	☐	☐	☐	23.	☐	☐	☐	☐	33.	☐	☐	☐	☐
4.	☐	☐	☐	☐	14.	☐	☐	☐	☐	24.	☐	☐	☐	☐	34.	☐	☐	☐	☐
5.	☐	☐	☐	☐	15.	☐	☐	☐	☐	25.	☐	☐	☐	☐	35.	☐	☐	☐	☐
6.	☐	☐	☐	☐	16.	☐	☐	☐	☐	26.	☐	☐	☐	☐	36.	☐	☐	☐	☐
7.	☐	☐	☐	☐	17.	☐	☐	☐	☐	27.	☐	☐	☐	☐	37.	☐	☐	☐	☐
8.	☐	☐	☐	☐	18.	☐	☐	☐	☐	28.	☐	☐	☐	☐	38.	☐	☐	☐	☐
9.	☐	☐	☐	☐	19.	☐	☐	☐	☐	29.	☐	☐	☐	☐	39.	☐	☐	☐	☐
10.	☐	☐	☐	☐	20.	☐	☐	☐	☐	30.	☐	☐	☐	☐	40.	☐	☐	☐	☐

For Skill-Centered Tests only, enter the numbers of all special questions and your answers in the spaces below.

Materials List for Reactions and Reason

Quantities listed are for a class of 30 students working in pairs.

*Optional Items. These items depend on teacher choice. We have listed substitutions in the experiment discussion. Consult the specific experiment in the teacher's guide to determine use and quantities.

NONEXPENDABLE MATERIALS

Item	*Experiment*	*Amount*
Aluminum foil	12*	small roll*
Aluminum nuts and bolts	7*	250 g*
Bags, clear plastic (sandwich size)	10	15
Balances, 0.01 g sensitivity	—	—
Balls, Styrofoam, 20-mm diameter	43	60
Balls, Styrofoam, 25-mm diameter	43	30
Beakers, 50-cm^3	2*, 32*	60*
Beakers, 150-cm^3	11, 37	15
Beakers, 250-cm^3	37	15
Beakers, 400-cm^3	13, 15, 22	30
Beakers, 600-cm^3	22	15
Brass fittings	7*	250 g*
Bunsen burners	—	15
Clamps, universal	13, 15, 23	30
Copper shot	7*	250 g*
Dropper bottles, or medicine droppers and small beakers	2*	60*
Evaporating dish, #0	11	15
Funnels, 75-mm diameter, with supports	11, 37	15
Glass beads *or* marbles	7*	250 g*
Graduated cylinders, 10-cm^3	7, 11, 13, 15	15
Graduated cylinders, 50-cm^3	7, 22	15
Graduated cylinders, 100-cm^3	37	15
Iron nails	7*	250 g*
Lead shot	7*	250 g*
Magnets, bar	10	15
Magnifying glasses	10, 11	15
Medicine droppers	2, 13, 15	60
Peas, dried	33	400 g
Rice, non-instant	33	200 g
Ring stands and rings	—	15
Rubber stoppers, #2, 1-hole	32	15
Rubber stoppers, #2, 2-hole	23	15
Rubber stoppers, #2, solid	7*	250 g*
Rubber tubing, heavy wall, 9-mm (3/8″) I.D. (15 lengths)	23, 32	900 cm
Spatulas	11	15
Stirring rods, glass	21, 22, 23, 37	15

NONEXPENDABLE MATERIALS (cont'd)

Item	*Experiment*	*Amount*
Test tubes, 13 × 100-mm	2, 13, 15	150
Test tubes, 18 × 150-mm	11, 32	60
Test-tube clamps	11, 21	15
Test-tube racks	2, 11, 32	15
Thermometers, −10°C to 110°C	13, 15	15
Toothpicks	43	1 box
Triangle, clay	11, 37	15
Vacuum pump and bell jar	16*	1*
Watch glasses, 90-mm diameter	22	15
Wire gauze, asbestos centers	11, 13, 18, 22, 37	15
Wire gauze, plain	18	15

EXPENDABLE MATERIALS

Item	*Experiment*	*Amount*
Acetone	22, 37	900 cm^3
Aluminum wire, 18-ga. or heavier	22	25 g
Ammonium hydroxide, conc.	2	20 cm^3
Boiling chips	13, 15	10 g
Bromocresol green	2	0.05 g
Calcium hydroxide	32	1 g
Can lids	11	15
Candles	11	15
Copper, metal turnings	21, 22	45 g
Copper(II) oxide	23	60 g
Copper sulfate, pentahydrate, $CuSO_4 \cdot 5H_2O$	2, 32	17 g
Cyclohexane	15*	250 cm^3*
Ethanol (ethyl alcohol)	15*	250 cm^3*
Filter paper, 12.5-cm diameter	11, 37	65 sheets
Glass tubing, 6–8-mm diameter	23	5 m
Graph paper, linear	13	60 sheets
Hydrochloric acid, conc.	2, 22, 32, 37	650 cm^3
Hydrogen peroxide, 3 percent	32	200 cm^3
Iodine, solid	11	10 g
Iron, metal powder	10	100 g
Lead chloride	11	30 g
Lead nitrate	2	8.2 g
Litmus paper, red and blue (or pH paper)	22*	15 vials each*
Manganese dioxide	32	10 g
Marble chips ($CaCO_3$)	32, 37	100 g
Methanol (methyl alcohol)	12*, 15*	275 cm^3*
2-methyl-2-propanol (*t*-butanol)	13, 15*	500 cm^3
Methylene blue *or* food coloring	12*	10 drops*

EXPENDABLE MATERIALS (cont'd)

Item	*Experiment*	*Amount*
Nitric acid, conc.	22	120 cm^3
pH paper, universal, wide range (or litmus paper, red and blue)	22	30 strips
Potassium iodide	2	8.5 g
Sand (SiO_2)	11	30 g
Sodium hydroxide	22	120 g
Sodium nitrate	11	50 g
Sulfur, flowers (powder)	10, 21	110 g
Test tubes, 18 × 150-mm (hard glass)	21, 23	30
Trichlorotrifluoroethane (TTE)	11	300 cm^3
Wood splints	32	30
Zinc, mossy	32	10 g
Zinc, 16–20-ga. sheet	2	300 cm^2

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Acknowledgments

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Table of International Relative Atomic Masses*

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.0	Mercury	Hg	80	200.6
Aluminum	Al	13	27.0	Molybdenum	Mo	42	95.9
Americium	Am	95	(243)**	Neodymium	Nd	60	144.2
Antimony	Sb	51	121.8	Neon	Ne	10	20.2
Argon	Ar	18	39.9	Neptunium	Np	93	237.0
Arsenic	As	33	74.9	Nickel	Ni	28	58.7
Astatine	At	85	(210)	Niobium	Nb	41	92.9
Barium	Ba	56	137.3	Nitrogen	N	7	14.0
Berkelium	Bk	97	(247)	Nobelium	No	102	(259)
Beryllium	Be	4	9.01	Osmium	Os	76	190.2
Bismuth	Bi	83	209.0	Oxygen	O	8	16.0
Boron	B	5	10.8	Palladium	Pd	46	106.4
Bromine	Br	35	79.9	Phosphorus	P	15	31.0
Cadmium	Cd	48	112.4	Platinum	Pt	78	195.1
Calcium	Ca	20	40.1	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.0	Potassium	K	19	39.1
Cerium	Ce	58	140.1	Praseodymium	Pr	59	140.9
Cesium	Cs	55	132.9	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.5	Protactinium	Pa	91	231.0
Chromium	Cr	24	52.0	Radium	Ra	88	226.0
Cobalt	Co	27	58.9	Radon	Rn	86	(222)
Copper	Cu	29	63.5	Rhenium	Re	75	186.2
Curium	Cm	96	(247)	Rhodium	Rh	45	102.9
Dysprosium	Dy	66	162.5	Rubidium	Rb	37	85.5
Einsteinium	Es	99	(254)	Ruthenium	Ru	44	101.1
Erbium	Er	68	167.3	Samarium	Sm	62	150.4
Europium	Eu	63	152.0	Scandium	Sc	21	45.0
Fermium	Fm	100	(257)	Selenium	Se	34	79.0
Fluorine	F	9	19.0	Silicon	Si	14	28.1
Francium	Fr	87	(223)	Silver	Ag	47	107.9
Gadolinium	Gd	64	157.3	Sodium	Na	11	23.0
Gallium	Ga	31	69.7	Strontium	Sr	38	87.6
Germanium	Ge	32	72.6	Sulfur	S	16	32.1
Gold	Au	79	197.0	Tantalum	Ta	73	180.9
Hafnium	Hf	72	178.5	Technetium	Tc	43	(97)
Helium	He	2	4.00	Tellurium	Te	52	127.6
Holmium	Ho	67	164.9	Terbium	Tb	65	158.9
Hydrogen	H	1	1.008	Thallium	Tl	81	204.4
Indium	In	49	114.8	Thorium	Th	90	232.0
Iodine	I	53	126.9	Thulium	Tm	69	168.9
Iridium	Ir	77	192.2	Tin	Sn	50	118.7
Iron	Fe	26	55.8	Titanium	Ti	22	47.9
Krypton	Kr	36	83.8	Tungsten	W	74	183.8
Lanthanum	La	57	138.9	Uranium	U	92	238.0
Lawrencium	Lr	103	(260)	Vanadium	V	23	50.9
Lead	Pb	82	207.2	Xenon	Xe	54	131.3
Lithium	Li	3	6.94	Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0	Yttrium	Y	39	88.9
Magnesium	Mg	12	24.3	Zinc	Zn	30	65.4
Manganese	Mn	25	54.9	Zirconium	Zr	40	91.2
Mendelevium	Md	101	(258)				

*Based on International Union of Pure and Applied Chemistry (IUPAC) values (1975).

**Numbers in parentheses give the mass numbers of the most stable isotopes.

PERIODIC TABLE OF THE ELEMENTS

1.008
H
Hydrogen
1

200.6 — atomic mass
Hg — symbol
Mercury — name
80 — atomic number

IA	IIA	IIIB	IVB	VB	VIB	VIIB	← VIIIB	VIIIB	VIIIB →	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
																	4.00 **He** Helium 2
6.94 **Li** Lithium 3	9.01 **Be** Beryllium 4											10.8 **B** Boron 5	12.0 **C** Carbon 6	14.0 **N** Nitrogen 7	16.0 **O** Oxygen 8	19.0 **F** Fluorine 9	20.2 **Ne** Neon 10
23.0 **Na** Sodium 11	24.3 **Mg** Magnesium 12											27.0 **Al** Aluminum 13	28.1 **Si** Silicon 14	31.0 **P** Phosphorus 15	32.1 **S** Sulfur 16	35.5 **Cl** Chlorine 17	39.9 **Ar** Argon 18
39.1 **K** Potassium 19	40.1 **Ca** Calcium 20	45.0 **Sc** Scandium 21	47.9 **Ti** Titanium 22	50.9 **V** Vanadium 23	52.0 **Cr** Chromium 24	54.9 **Mn** Manganese 25	55.8 **Fe** Iron 26	58.9 **Co** Cobalt 27	58.7 **Ni** Nickel 28	63.5 **Cu** Copper 29	65.4 **Zn** Zinc 30	69.7 **Ga** Gallium 31	72.6 **Ge** Germanium 32	74.9 **As** Arsenic 33	79.0 **Se** Selenium 34	79.9 **Br** Bromine 35	83.8 **Kr** Krypton 36
85.5 **Rb** Rubidium 37	87.6 **Sr** Strontium 38	88.9 **Y** Yttrium 39	91.2 **Zr** Zirconium 40	92.9 **Nb** Niobium 41	95.9 **Mo** Molybd'm 42	(97) **Tc** Technetium 43	101.1 **Ru** Ruthenium 44	102.9 **Rh** Rhodium 45	106.4 **Pd** Palladium 46	107.9 **Ag** Silver 47	112.4 **Cd** Cadmium 48	114.8 **In** Indium 49	118.7 **Sn** Tin 50	121.8 **Sb** Antimony 51	127.6 **Te** Tellurium 52	126.9 **I** Iodine 53	131.3 **Xe** Xenon 54
132.9 **Cs** Cesium 55	137.3 **Ba** Barium 56	138.9 **La*** Lanthanum 57	178.5 **Hf** Hafnium 72	180.9 **Ta** Tantalum 73	183.8 **W** Tungsten 74	186.2 **Re** Rhenium 75	190.2 **Os** Osmium 76	192.2 **Ir** Iridium 77	195.1 **Pt** Platinum 78	197.0 **Au** Gold 79	200.6 **Hg** Mercury 80	204.4 **Tl** Thallium 81	207.2 **Pb** Lead 82	209.0 **Bi** Bismuth 83	(209) **Po** Polonium 84	(210) **At** Astatine 85	(222) **Rn** Radon 86
(223) **Fr**† Francium 87	226.0 **Ra** Radium 88	(227) **Ac**** Actinium 89	‡ 104	‡ 105	‡ 106												

*	140.1 **Ce** Cerium 58	140.9 **Pr** Praseody'm 59	144.2 **Nd** Neodymium 60	(145) **Pm** Promethium 61	150.4 **Sm** Samarium 62	152.0 **Eu** Europium 63	157.3 **Gd** Gadolinium 64	158.9 **Tb** Terbium 65	162.5 **Dy** Dysprosium 66	164.9 **Ho** Holmium 67	167.3 **Er** Erbium 68	168.9 **Tm** Thulium 69	173.0 **Yb** Ytterbium 70	175.0 **Lu** Lutetium 71
**	232.0 **Th** Thorium 90	231.0 **Pa** Protactinium 91	238.0 **U** Uranium 92	237.0 **Np** Neptunium 93	(242) **Pu** Plutonium 94	(243) **Am** Americium 95	(245) **Cm** Curium 96	(245) **Bk** Berkelium 97	(251) **Cf** Californium 98	(254) **Es** Einsteinium 99	(254) **Fm** Fermium 100	(256) **Md** Mendel'm 101	(254) **No** Nobelium 102	(257) **Lr** Lawrencium 103

†The most stable known isotopes are shown in parentheses.

‡The discovery of elements 104, 105, and 106 has been claimed by both American and Soviet scientists. The Americans have suggested the name *rutherfordium* and *hahnium* for 104 and 105; the Soviets have suggested the names *kurchatovium* and *nielsbohrium* for these same elements. No name has yet been proposed for element 106.

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