LABORATORY SAFETY FOR CHEMISTRY STUDENTS

ROBERT H. HILL, JR.
DAVID C. FINSTER

WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

LABORATORY SAFETY FOR CHEMISTRY STUDENTS

LABORATORY SAFETY FOR CHEMISTRY STUDENTS

ROBERT H. HILL, JR.
DAVID C. FINSTER

WILEY

A JOHN WILEY & SONS, INC., PUBLICATION

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data:

Hill, Robert H., 1945-
Laboratory safety for chemistry students / Robert H. Hill, Jr., David C. Finster.
p. cm.
Includes index.
ISBN 978-0-470-34428-6 (pbk.)
1. Chemical laboratories–Safety measures. I. Finster, David C., 1953- II. Title.
QD51.H55 2010
542.028′9–dc22
2009052126 h

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

To those who have suffered personal loss, injuries, and even death in laboratory incidents that were preventable. May we use the knowledge from these incidents to teach the next generation of scientists about laboratory and chemical safety.

CONTENTS

PREFACE: TO THE STUDENTS

THERE IS probably no single course in "laboratory safety or chemical safety" at your college or university. Why not? Chemistry curricula have developed over many decades with a focus on the main topics of chemistry: organic, inorganic, physical chemistry, analytical chemistry, and (more recently) biochemistry. For decades, the topic of chemical safety was included at the margins of lab courses, mostly taught in a small way as a footnote to various lab experiments and procedures. Some chemists and chemistry teachers were aware of the importance of safety, while many were not. In the late twentieth century, and now even more in the twenty-first century, for a variety of legal, ethical, and educational reasons, the topic of chemical safety has been taught much more, but it is still not considered by most as "mainstream content area" of chemistry. The absence of good resources (a void we hope this book fills) contributed to this stature. In summary, many chemistry faculty simply don't consider instruction in laboratory and chemical safety to be very important—or at least important enough to devote a whole course to the topic.

While this textbook could easily be used as a primary textbook for a course in chemical safety, the authors actually strongly prefer that it be used instead throughout the curriculum. We believe that safety instruction is so important that it should be included in *all chemistry laboratory courses*. Additionally, the small "bites" of lab safety included among the 70 sections used separately over an extended four-year period provide constant reinforcement of the importance of safety that nurtures a strong safety ethic. This book has been written with that use in mind.

How so? As you will see, the eight chapters in the book are "layered" in three tiers, with a variety to topics suited to introductory, intermediate, and advanced courses. Each section presents information on a "need to know" basis. For example, there's actually a lot to know about wearing gloves in labs, but you don't need to know everything right away. The first section about gloves is written for introductory courses; a later section is written for organic and advanced students. The same is true for eye protection and for chemical hoods. In this regard, the book is structured unlike any other college textbook you've ever seen. It really is a book that will last for four years (and beyond).

We expect that most of the sections in this book will be tied to various experiments that you are conducting in labs. Again, let's learn what we need to learn on a "need to know" basis. Working with flammable chemicals? Read about solvents and fires. Working with a strong acid or oxidizing agent? Read about corrosives. Worried about lab emergencies or lab incidents? Read about emergency response. This may be the most practical textbook you use in college!

Why should you learn about safety? Well, to stay safe, of course, in the laboratory. This reason alone is enough, but there are additional advantages to knowing about safety. First, it's cheap. Accidents always cost more money than whatever is spent on safety equipment and materials that help prevent these incidents. Second, being safe prevents injuries, damage to health, perhaps even death, and these outcomes have costs that obviously go beyond money. Third, it's environmentally responsible. Knowing how to use chemicals and dispose of wastes legally and appropriately is being environmentally conscious (in a way, frankly, that the chemical industry was not for many decades in the twentieth century). Fourth, you develop habits that will make you a valuable employee someday. Chemical companies now understand, better than many colleges and universities, that being safe is the soundest financial practice a company can adopt. And as more laws and regulations have been developed over the past several decades, employers and employees really have no choice about many aspects of laboratory safety. Your understanding of this situation, upon graduation, will make you an attractive candidate for a job.

While much of this book is very practical and "informational" in nature, some early sections discuss the issue of one's mental attitude about safety, which may seem more philosophical in nature at first. But, in reality, adopting a positive attitude about safety is *the* most important, practical step you can take to be safe. With this mindset, all other actions in a laboratory are performed only after stopping to think about hazards and risks and the means by which you can stay safe in the lab.

We hope you find this book valuable as part of your chemical education. As chemists, the authors have the same passion for chemistry as do your teachers. Understanding nature through the "filter of chemistry" provides great insight and intrinsic joy to most chemists, in addition to the tremendous power of chemistry to improve the quality of the human condition. We are passionate about safety, too, and hope that your time in the lab is both intellectually rewarding and safe! There is much to learn, as the size of this book indicates, and the book offers not much more than an introduction to most topics. We hope that you continue your "safety education" long after you graduate from college.

Finally, you will notice that each section begins with an "Incident". Stories are powerful, and often memorable, ways to learn a principle or to reveal a danger. We hope you find these incidents useful and we encourage you to share your story about safety with us! Hopefully, the story is a happy one about what "almost happened" (although you will see that most of our incidents are not "near misses"). If you have a story that will help some future student learn from your experience, please contact us at dfinster@wittenberg.edu or roberth_hill@mindspring.com. Maybe your story will be in the next edition of the book! We'd also like to hear how you like the book or have suggestions for improvement. Stay safe!

Robert H. Hill, Jr.
David C. Finster

Atlanta, Georgia
Springfield, Ohio
March 2010

TO THE INSTRUCTOR

Purpose

THE PRINCIPAL purpose of this textbook is to provide a resource that can be used to help teach undergraduate chemistry students the basics of laboratory and chemical safety. This textbook is not designed for a single course but rather its concept is to use short sections in laboratory sessions (or perhaps some lecture sessions) over the four years of undergraduate study. It can be used as a companion text for each laboratory chemistry course throughout the curriculum, including research, using specific sections that fit the topics and hazards of the laboratory experiments.

It is the vision and hope of the authors that if the chemistry academic community has a textbook about laboratory and chemical safety that they will use parts or all of it in the laboratory or classroom curriculum. This book was written from the heart as a result of a passion for laboratory and chemical safety. The authors recognize, as do many others, that there is a need to improve the level of knowledge and education about laboratory and chemical safety among new and upcoming chemists and other laboratory scientists who work in laboratories and handle chemicals and other hazardous materials in their operations.

We believe that laboratory and chemical safety should be integral parts of the entire chemistry educational process, touching virtually all fields of chemistry, since we see laboratory and chemical safety as subdisciplines of the field of chemistry that cross-cuts virtually all areas of chemistry. Thus, teaching safety is a long-term effort that requires attention as each area of chemistry is introduced and advances so that a strong knowledge and positive attitude toward laboratory and chemical safety can be developed. Our approach is to teach laboratory and chemical safety in small sections throughout the chemical education process. This iterative process is practical from a learning point of view and sends the message to students: safety is always important.

Audience

This textbook is written primarily for undergraduate chemistry students, but we believe other laboratory science students, scientists, technicians, and investigators will also find it useful. Many graduate and working chemists will find this book useful since it is likely that they are unfamiliar with the level of laboratory and chemical safety education found in this book. Those working in industrial, government, and other independent laboratory situations will also find this book useful. Although designed as a teaching tool and not a resource text, it can serve in the latter capacity and contains many references to other resources.

Scope

This book is broad in scope since it introduces most areas of laboratory and chemical safety. This book is not a comprehensive treatise on laboratory and chemical safety and it does not go into great detail with specific procedures or methods. It presents various topics on a "need to know" basis, targeting different levels of instruction throughout a chemistry curriculum. This book will help chemists and other scientists use four simple principles of laboratory and chemical safety to:

1. **R**ecognize hazards;
2. **A**ssess the risks of those hazards;
3. **M**inimize, manage, or control those hazards; and
4. **P**repare to respond to emergencies.

We use the acronym RAMP to remind the student of these principles—RAMP up for safety.

Unique Approach and Organization

This is a unique textbook designed to be used throughout the four years of undergraduate study. Topics are targeted toward each level (year) of study by the students over their undergraduate experience. Topically, it is divided into eight chapters, and further into 70 sections for introductory (year 1) intermediate (year 2) and advanced topics (years 3 and 4).

- Chapter 1 Principles, Ethics, and Practices
- Chapter 2 Emergency Response
- Chapter 3 Understanding and Communicating About Laboratory Hazards
- Chapter 4 Recognizing Laboratory Hazards: Toxic Substances and Biological Agents
- Chapter 5 Recognizing Laboratory Hazards: Physical Hazards
- Chapter 6 Risk Assessment
- Chapter 7 Minimizing, Controlling, and Managing Hazards
- Chapter 8 Chemical Management: Inspections, Storage, Wastes, and Security

Each section begins with a preview, a quote, and a laboratory incident that asks "What lessons can be learned from this incident?" This is followed by the text that is relevant to the topic and incident with references that often contain links to the Internet. Dispersed through out the book are *Chemical Connections* that seek to demonstrate how safety uses chemical principles and *Special Topics* that seek to explain relevant topics of interest to a particular section. Each section also concludes with a series of multiple choice questions about the topic.

Safety, like other disciplines, is principle driven. The student must be encouraged to use critical thinking in applying safety principles and practices to conduct chemical work safely and to identify the need for additional information about the safety in operations handling chemicals or other hazardous agents.

How This Book Can Be Used

We anticipate several ways in which the book may be used. It may be used directly by the student and taught by an instructor. However, the authors are well aware of the difficulty of adding more to the curriculum and believe that each section can be used as a prelaboratory assignment session. The student can be directed to go to a web site to take an electronic quiz for each section with results going to the laboratory instructor to ensure that each student has been successful in understanding the basic topics presented in a section before the laboratory session.

More specifically, we anticipate two models for using the sections as prelab assignments:

1. An instructor can assign a reading and electronic quiz, and do little more. This practice alone may represent an improvement in safety instruction, requires virtually no additional work on the part of the instructor and no allocation of class/lab time, and provides some form of assessment of student learning.
2. An instructor can assign a reading and the electronic quiz, and follow this up in a prelab session with discussion of the topic, probably making specific reference to the experiment of the day,

which is likely to be related to the safety topic. The degree to which the instructor elaborates on the topic can be considerable. Discussion questions and "what if" scenarios are easy to develop. The value of the book is that precious lab time is not spent on "covering the basics" and "information transfer." Students will come to the lab with some background knowledge, which allows for a more productive, and likely more sophisticated, discussion of a particular safety topic.

Ultimately, our goal in providing this resource is to minimize, if not eliminate, the activation energy barrier that prevents many faculty from discussing safety more in their classes and labs. The excuse that "there's not enough time" is eliminated when no class or lab time, in the first model above, is used. The excuse that "I'm not trained in safety" is eliminated since the book provides the expertise and thoughtful presentation of the safety topics. The American Chemical Society Committee on Professional Training requires (as stated in the Guidelines and Evaluation Procedures for Bachelor's Degree Programs) the "approved programs should promote a safety-conscious culture in which students understand the concepts of safe laboratory practices and how to apply them." Use of this book meets that learning goal.

Ideally, this book would be purchased in the first year for chemistry majors and used as a supplementary text throughout the entire undergraduate chemistry curriculum. However, the authors recognize that many students in introductory courses are not chemistry majors and will not continue in the chemistry curriculum. Using the Wiley Custom Select option, there is also the opportunity to make single sections of the book available for clustering in faculty—designed packets that are individually suited to particular teachers, courses, and/or campuses. This will be at an attractive price that makes use of the packets reasonably as a supplementary purchase for students. The strategy can be pursued throughout the curriculum, although at some point the purchase of the entire book, particularly for chemistry majors, would seem prudent.

ACKNOWLEDGMENTS

WE THANK all our friends and colleagues for their support and encouragement during the writing of this text; the value of this support is indeterminable. We also recognize those who took a more active role in helping us review the many sections of the book and who provided some stories of incidents and some of our figures. The following list highlights those who have helped us in one or more ways. Their input and unbiased criticism has been invaluable and has helped us create a much better text. We thank:

Janice Ashby, Centers for Disease Control and Prevention

David Ausdemore, Centers for Disease Control and Prevention

Emily Bain, Kenyon College

Kathy Benedict, University of Illinois, Urbana-Champaign

George Bennett, Millikin University

Mark Cesa, INEOS USA, LLC

Debbie Decker, University of California, Davis

Larry Doemeny, ACS Committee on Chemical Safety

Amina El-Ashmawy, Collin County Community College

Harry Elston, Midwest Chemical Safety LLC

Barbara Foster, University of West Virginia

Cheryl Frech, University of Central Oklahoma

Ken Fivizzani, ACS Committee on Chemical Safety

Jean Gaunce, Centers for Disease Control and Prevention

Pete Hanson, Wittenberg University

Dennis Hendershot, Center for Chemical Process Safety

Mary Hill, Memorial University Medical Center

Bill Howard, Centers for Disease Control and Prevention

David Katz, Pima Community College

Neal Langerman, Advanced Chemical Safety

Mark Lassiter, Montreat College

Gary Miessler, St. Olaf College

Larry Needham, Centers for Disease Control and Prevention

Rick Niemeier, National Institute for Occupational Safety and Health

Alice Ottoboni, Retired, California State Department of Public Health

Les Pesterfield, Western Kentucky University

Russ Phifer, WC Environmental, LLC

Gordon Purser, University of Tulsa

Jonathan Richmond, Jonathan Richmond & Associates, Inc.

Joyce Rodriguez, Centers for Disease Control and Prevention

Eileen Segal, Retired

Linda Stroud, Science & Safety Consulting Services

Ralph Stuart, University of Vermont

Erik Talley, Weill Cornell Medical College

Paul Voytas, Wittenberg University

Doug Walters, Environmental and Chemical Safety Educational Institute

Stefan Wawzyniecki, University of Connecticut

Mark Wilson, Centers for Disease Control and Prevention

Frankie Wood-Black, Trihydro

Tim Zauche, University of Wisconsin—Platteville

These people share our enthusiasm and passion for improving laboratory and chemical safety among our new and upcoming scientists.

We also thank the students enrolled in the following courses at Wittenberg University in Spring 2009 who provided feedback for early versions of many sections of the book: Chemistry 162, Chemistry 281, Chemistry 302, Chemistry 321, and Chemistry 372.

And finally, we thank our families without whose support and understanding this work would have not been possible.

R. H. H., Jr.
D. C. F.

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienist
ACS	American Chemical Society
AIDS	Acquired immunodeficiency syndrome
ALARA	As low as reasonable achievable
APHIS	Animal and Plant Health Inspection Service
ANSI	American National Standards Institute
ASSE	American Society of Safety Engineers
BBP	Blood-borne pathogens
BEI	Biological exposure index
BLEVE	Boiling liquid expanding vapor explosion
BMBL	Biosafety in Microbiological and Biomedical Laboratories
BSL	Biosafety Levels
CAS	Chemical Abstracts Service
CCW	Counterclockwise
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CHO	Chemical Hygiene Officer
CHP	Chemical Hygiene Plan
CLIPS	Chemical Laboratory Information Profiles
CNS	Central nervous system
CPR	Cardiopulmonary resuscitation
CSB	U.S. Chemical Safety and Hazard Investigation Board
CW	Clockwise
DOL	Department of Labor
DHS	Department of Homeland Security
DOT	Department of Transportation
ELF	Extremely low frequency
EMF	Electromagnetic frequency
EMT	Emergency medical technician
EPCRA	Emergency Planning and Community Right-to-Know Act
EPA	U.S. Environmental Protection Agency
FAS	Fetal alcohol syndrome
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GFCI	Ground fault circuit interrupters
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
HAZWOPER	Hazardous Waste Operations and Emergency Response
HBV	Hepatitis B virus
HEPA	High efficiency particulate air
HHS	Department of Health and Human Services
HVAC	Heating, vacuum, and air conditioning
IARC	International Agency for Research on Cancer
IDLH	Immediately dangerous to life and health
IEC	International Electrotechnical Commission
IR	Infrared
LCSSs	Laboratory Chemical Safety Summaries
MRI	Magnetic resonance imaging
MSDS	Material Safety Data Sheet
NFPA	National Fire Protection Association
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NMR	Nuclear magnetic resonance
NRC	Nuclear Regulatory Commission
NSF	National Sanitation Foundation (can also be National Science Foundation)
NTP	National Toxicology Program
OEL	Occupational exposure limit
OJT	On the job training

OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PHA	Process hazard analysis
PSM	Process Safety Management of Highly Hazardous Materials
RCA	Root Cause Analysis
RCRA	Resource Conservation and Recovery Act
RAMP	Recognize, Assess, Minimize, Prepare
REL	Recommended exposure limit
RF	Radio frequency
SDS	Safety Data Sheet
SI	Système International
STEL	Short-term exposure limit
SWDA	Safe Water Drinking Act
TLV	Threshold Limit Value
TSCA	Toxic Substances Control Act
TWA	Time-weighted average
UL	Underwriter's Laboratory
USDA	U.S. Department of Agriculture
UV	Ultraviolet
VLF	Very low frequency
WHO	World Health Organization
RSO	Radiation Safety Officer
RSP	Radiation Safety Program
RSC	Radiation Safety Committee
SCBA	Self-contained breathing apparatus

CHAPTER 1

PRINCIPLES, ETHICS, AND PRACTICES

THERE ARE hundreds of "things to learn about safety." But, without some framework into which to place all of this information, it just becomes rules and guidelines that are too easy to forget over time. Understanding the reasons *why* safety is important is crucial to understanding the reasons that stand behind the facts, rules, and guidelines. This chapter introduces the *safety ethic* and the *four principles of safety* that reappear in most sections of the book. We also present three sections about green chemistry, which implies a strong connection between this new way to think about environmentally responsible chemistry and chemical safety. Finally, the Level 3 topics discuss various aspects of safety that may seem less relevant to you, a student, but become very important in your life as a chemist after college when you move into the working world of chemistry.

INTRODUCTORY

1.1.1 The Four Principles of Safety Discusses the importance of safety in the laboratory and introduces the *four principles of safety* and *the student safety ethic*.

1.1.2 What Is Green Chemistry? Introduces the fundamental tenets of green chemistry and discusses how these principles can used in the college chemistry curriculum.

INTERMEDIATE

1.2.1 Rethinking Safety: Learning from Laboratory Incidents Describes how you can learn lessons from a critical analysis of an incident using the "five whys."

1.2.2 Green Chemistry in the Organic Curriculum Discusses applications of green chemistry in organic chemistry laboratories.

ADVANCED

1.3.1 Fostering a Safety Culture Discusses approaches to establishing and promoting a strong safety culture among those people who are working under your supervision or leadership.

1.3.2 Employers' Expectations of Safety Skills for New Chemists Provides suggestions about what employers might expect in safety skills for new employees (new graduates) who begin working in their facilities.

1.3.3 Laws and Regulations Pertaining to Safety Provides a brief overview of the laws and regulations pertaining to safety and chemicals in the laboratory.

1.3.4 Green Chemistry—The Big Picture Reviews selected principles of green chemistry that apply most directly to laboratory safety.

1.1.1

THE FOUR PRINCIPLES OF SAFETY

Preview This section discusses the importance of safety in the laboratory and introduces the *four principles of safety* and *the student safety ethic*.

> *The greatest discovery of my generation is that a human being can alter his life by altering his attitudes of mind.*
>
> William James, American physician, philosopher, and psychologist (1842–1910)[1]

INCIDENT 1.1.1.1 MIXING ACID AND WATER[2]

John was doing an experiment that required the use of dilute sulfuric acid. The instructor said that students should mix 1 part of concentrated sulfuric acid with 4 parts of water and that everyone should always *add acid to water* and not water to acid. John was not paying attention when the instructions were given and he added water to acid. There was a violent popping noise, the beaker became hot, and a mist formed over the solution, and some solution splattered out onto his skin and his partner's skin.

What lessons can be learned from this incident?

Hazards and Risks

This book was written to teach you how to work safely in the laboratory. To be safe in the laboratory or elsewhere, you need to do only four things:

- *R*ecognize hazards.
- *A*ssess the risks of hazards.
- *M*inimize the risks of hazards.
- *P*repare for emergencies.

We will use the acronym RAMP as a mnemonic guide to remember: *recognize, assess, minimize, prepare*. This will be a recurring theme in this book. Let's see how these four steps make sense by considering various aspects of safety.

Safety is freedom from danger, injury, or damage. Being safe requires actions by *you* and by others. When you decide to adopt safety as an integral part of your college laboratory experiences it means that you always seek to do those things that prevent incidents that might cause injury and harm. This sounds easy, but when doing chemistry experiments in laboratories, it is often easier to get "caught up" in the procedures and trying to understand what you are doing and to forget about making sure you're doing it safely. Throughout this book, each section will start with a real incident that describes a dangerous episode in a laboratory. All of the people in these incidents are "just like you." They had some safety education (just as you will experience) but were not thinking about safety when something bad happened.

Let's explore some basic ideas about risks and hazards and how to prevent incidents in laboratories.

A *hazard* is a potential source of danger or harm. The word *potential* means something that is capable of being dangerous or harmful. Many chemicals may have inherent hazardous properties and

---

Laboratory Safety for Chemistry Students, by Robert H. Hill, Jr. and David C. Finster

these hazardous properties never change. The practice of safety is really about minimizing, managing, or controlling these hazards. You'll learn a great deal in this book and in your chemistry courses about various categories of chemicals and the hazards they pose.

Risk is the probability of suffering harm from being exposed to a hazard or unsafe situation. The level of risk depends on many things beyond the inherent hazard of a chemical. For example, the amount of the chemical, the form it is in (gas, liquid, or solid), and how you handle the chemical all affect the level of risk.

Exposure means coming in direct contact with a hazard or chemical in a fashion that causes injury or harm. A dose is the amount that you might ingest, breathe, or spill on your skin. An exposure might also arise from a fire or explosion. The dose, the length of exposure, and the path of exposure play significant roles in the extent of harm. The important thing to remember is that we want to minimize or eliminate exposure to hazards.

Hazards Are a Part of Our World!

Many things present hazards or have hazardous properties, but we have learned to use them safely every day. Often, the very properties that make chemicals useful are also the same properties that make them hazardous (see Figure 1.1.1.1). Just because something is hazardous does not mean that we would want to stop using it. In fact, our lives and our comfort often depend on the use of chemicals and equipment with hazardous properties. Let's look at an example of one of the most common chemical hazards that most of us encounter frequently.

Gasoline is extremely flammable and under the right conditions it can easily catch fire or even explode. Yet we use gasoline in our cars everyday without experiencing its potential adverse effects because we have *recognized* its hazardous properties, *assessed* how we could be exposed, developed methods to effectively *minimize* or control this hazard, and learned how to *prepare* for and handle emergencies with gasoline. We go to gas stations that store thousands of gallons of gasoline in tanks under our feet, we pump gallons of gasoline into our cars, and we routinely drive around with gallons of gasoline in the car's gas tank near us. The very properties that make gasoline hazardous are the same properties that make it useful. We have learned how to use this hazardous substance safely.

Can you think of materials or things that have hazardous properties that are very useful to us but can present a hazard to us if we are careless with them or mishandle or misuse them? Do you think that most 21st century citizens would approve of pumping a high-pressure, explosive chemical that can deprive you of oxygen in high concentrations into their homes? Probably not! But many of us do this when we use natural gas. What about electricity? What is the hazard? What is the overall risk? Common hazards are generally viewed as being less risky than uncommon hazards. Most hazards in the laboratory, even though they are "uncommon" at first, are no more dangerous than these common hazards encountered in our daily lives.

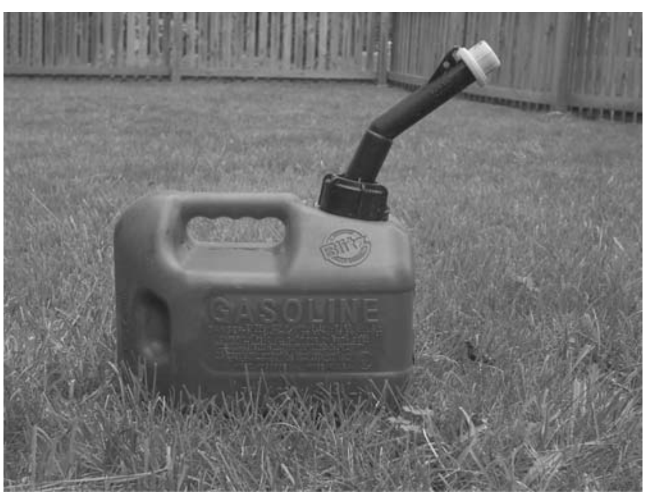

FIGURE 1.1.1.1 A Gallon of Gasoline. There are many hazardous chemicals in and around our homes, although we might treat them as more hazardous in a lab than in the home since we are so used to them at home.

Safety from the Experts

Three factors have been identified by Geller that contribute to safety: (1) *environmental factors* including facilities, location, equipment, procedures, and standards; (2) *person factors* including attitude, beliefs, personality, knowledge, skills, and abilities; and (3) *behavior factors* including safe and risky practices.[3] These factors are interconnected so that each factor influences others. Suppose, for example, that you see someone fall over something that was out of place, an environmental factor. You think to yourself (a personal factor), "I need to be more careful about things on the floor that I might trip over." When you see a wastepaper basket out of place in an aisle, you move it to its place out of the way (a behavior factor).

Being safe requires attention to all three factors since they have significant influence on your safety. If your college laboratory is safe and you observe other students and teachers there working safely by observing safety rules and safe practices, then you will begin to adopt an attitude that "safety is important in the laboratories and I want to be safe, too."

How Do We Learn Safety?

Safety is an empirical discipline. This means that we often learned how to be safe from past mistakes and incidents. Experience can teach us a lot, but if you learn safety by making a lot of your own mistakes, you may not survive for long! Most of us do not want to have to personally experience fires, explosions, toxic exposures, or other potentially dangerous incidents. Instead, we should be learning safety guidelines that have developed from the adverse experiences of others.

We can reduce our exposure to hazards through continuous and diligent efforts to include considerations about safety in our daily decisions. This simply involves thinking about safety and taking steps to prevent incidents, especially in the laboratory. Unfortunately, there is rarely positive feedback for being safe, but there is often negative feedback for *not* being safe. The consequence of exposure to unnecessary risk is likely to be injury or harm to you or others.

It's All About Minimizing Risk!

To maintain a safe lab environment, it is critical that everyone minimizes and/or eliminates the risk of exposure to hazards. We do this everyday with precautions that we have learned to prevent or reduce injury and harm. Table 1.1.1.1 shows common risk factors associated with these risks and proven risk reduction actions.[4–6] For example, if we wear seat belts, we are less likely to sustain life-threatening injuries in a collision. The phrase "less likely" is important because wearing a seat belt does not guarantee that you will be injury-free if you are in a collision, but it does mean that your chances of

TABLE 1.1.1.1 Common Risks, Risk Factors, and Risk Reduction Actions[4–6]

Common risks	Risk factors	Risk reduction actions
Cardiovascular disease, death from—heart disease and stroke, 1st and 3rd leading causes of death	High blood pressure, high blood cholesterol	A 12–13 point reduction in blood pressure decreases cardiovascular diseases by 25%; a 10% decrease in total blood cholesterol decreases coronary disease up to 30%
Lung cancer, death from	Cigarette smoking—early death: 22 times higher for male smokers; 12 times higher for female smokers	Stop cigarette smoking
Vehicle accidents, death from	No seat belt use; alcohol-impaired driving	Seat belt use laws; seat belt enforcement laws; sobriety checkpoints; reducing blood alcohol concentration to 0.08%; minimum legal drinking age laws

survival are better if you wear a seat belt. And they will be even better if you observe other public safety rules, such as driving within the speed limit and using defensive driving techniques.

Similarly, you will be required to wear splash goggles when working in the laboratory in order to reduce the risk of injury to your eyes from chemical splashes. The goggles don't guarantee that you will not be injured but experience has shown that wearing splash goggles significantly reduces the chance of injury to your eyes. And, when combined with other safety measures like using a hood or face shield or wearing gloves, risks are decreased even more.

Taking Unnecessary Risks: The Cause of Most Incidents

An important cause of many injuries and incidents is taking unnecessary risks; this is sometimes called practicing at-risk behavior.[7] Unnecessary risks are actions that violate safety principles, safety rules, and safe practices. If you can avoid taking unnecessary risks, you will likely prevent or reduce chances of an incident.

Why would someone take unnecessary risks? Someone may make a willful decision to violate rules, may unconsciously act based on past experiences, or may be unaware of a risk. Examples of unnecessary risk behavior are speeding, not wearing a seat belt, smoking cigarettes, overeating, not exercising, using illicit drugs, or skipping safety steps, such as deciding not to wear protective equipment needed for the job. In the laboratory such behavior includes not wearing safety goggles, eating or drinking in the laboratory, wearing inappropriate clothing, or taking unnecessary chances with hazards.

Avoiding unnecessary risks is not always easy. Often it means resisting human nature that causes us to do things that are convenient, comfortable, or expedient. Some people have learned through experience that if they cut corners they can save time and resources, and they sometimes can do this without negative consequence. That is, they get away with violating safety principles and they begin to think that it is okay to do something that is inherently unsafe or dangerous. This becomes a bad habit. As they get more careless and violate more rules and principles, they increase their chances of having an incident.

Types of Laboratories: Teaching, Research, and Industry

In the first few years of college, most laboratories in science courses are "cookbook" laboratories. By this we mean that students read and follow a set of laboratory instructions in order to perform an experiment to collect data. There are many variations on this theme but beginning students mostly "just follow instructions." Some experiments might involve elements of experimental design but this will be fairly limited in your early science laboratory courses. Because new students don't have to design experiments, they also don't have to think about designing good safety procedures into laboratory experiments because that has already been done by the author of the procedure. Unfortunately, in a sense, students get trained *not* to think as much about safety because they assume, with justification, that laboratory experiments that they are doing are already "safe."

In some upper-level courses and in undergraduate research laboratories, students start to participate in the design of laboratory experiments, usually under the watchful eye of an instructor or research mentor. For these experiences, it is very important to consider the safety of a procedure in the process of designing a new experiment.

Chemists with undergraduate degrees who enter a graduate program or work in an industrial laboratory setting become far more independent with regard to the design and implementation of laboratory experiments, so the burden for designing safe experiments rests heavily with the chemist in the laboratory. Many incidents occur in laboratories with relatively new chemists or graduate students running new experiments under situations where a thorough assessment of the hazards and risks was not undertaken.

It is the goal of this book to help educate chemistry students to work and function safely in laboratories. We will not focus much on the design of experiments in the early sections of each chapter since newer students don't design experiment and we believe that it is best to carefully focus on the hazards for the experiments that are to be encountered. In later sections in each chapter we will address more "advanced" topics, including considering safety in the design of an experiment and more in-depth discussions of hazards and other safety topics.

The Four Principles of Safety

We introduced RAMP (*recognize, assess, minimize, prepare*) above. Let's look at each of these steps using the language of hazards and risks. (See Figure 1.1.1.2.)

The first principle, to *recognize the hazards of chemicals, equipment, and procedures*, requires that you know and recognize the hazards of the chemicals that you are using. Sounds simple, right? Well, depending on your knowledge, it can be a very challenging process. There are millions of chemicals, of course, and knowing the hazards of all of them is not possible. But, we are helped in two ways.

First, most chemicals will fall into one (or two) of a handful of categories that have generally known hazards. To understand these hazards you must first understand the terminology and information that describes these various chemical properties. What does "flammable" mean? What is "toxic" or "corrosive"? And, how will you know if a chemical has any of these properties?

Second, and more specifically, "getting to know your chemical" requires that you review and understand available information about its hazards, such as container labels, Material Safety Data Sheets (MSDSs, see Section 3.1.3), reference books, online hazard information, and talking with experienced people.

Chapters 3–5 address these issues about hazards of chemicals in laboratories.

The second principle, *assess risks of hazards associated with exposures and procedures*, is perhaps the most important of all the principles.[4] This requires that you consider what kind of exposure to various chemicals could or will occur during a procedure or reaction as well as the risk associated with the use of equipment. Is this reaction exothermic (releasing energy) in a way that might lead to a fire or explosion? Are there any flammable chemicals involved that might pose a fire hazard? What is the chance of some exposure to a toxic chemical?

It is important *not to underestimate risks*, particularly in "familiar" situations.[2] This book and the chemistry courses that you take will help you learn to make good judgment about risks. Chapter 6 discusses this topic in more detail.

The third principle, *minimize risks*, requires careful attention to both the design and execution of an experiment. This requires that you take whatever reasonable steps are necessary to minimize, manage, or eliminate your exposure to a hazard by using good laboratory safety practices. This can only be done after a careful consideration of risk. The key steps in minimizing risk are designing and performing experiments with safety in mind, using personal protective equipment (such as splash goggles) and other safety equipment (such as chemical hoods), and applying good housekeeping practices. Many accidents are caused by sloppy and cluttered work areas. Chapter 7 discusses how to manage and minimize risks in laboratories.

Finally, despite efforts to prevent incidents (accidents) and exposure in the laboratory, it is prudent to prepare for them. Thus, we present the fourth principle: *prepare for emergencies*. What kinds of emergencies can happen in a laboratory? Fires, explosions, exposures to chemicals, personal injuries—all the sorts of hazards that have already been considered! Preparing for emergencies involves knowing what safety equipment is readily available and how to operate it (see Figure 1.1.1.3). You also need to

The Four Principles of Safety

Recognize Hazards
Assess Risks
Minimize Hazards
Prepare for Emergencies

FIGURE 1.1.1.2 The Four Principles of Safety. These four principles appear in nearly every section of this book. Memorizing, and using, these ideas whenever you think about safety issues will lead to "incident-free" laboratories.

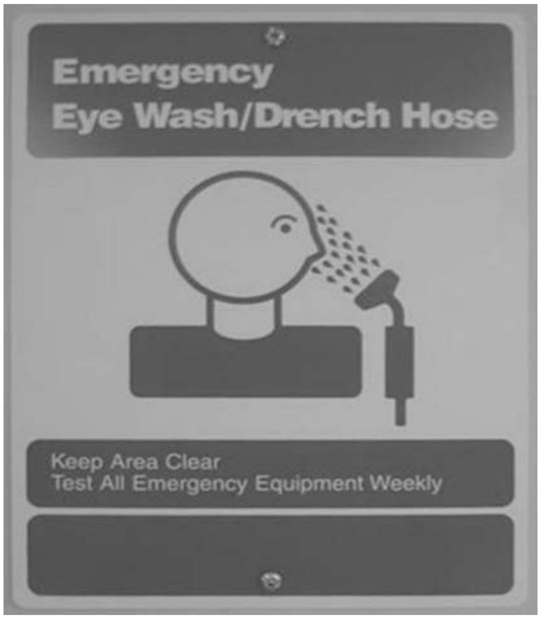

FIGURE 1.1.1.3 Eyewash Safety Sign. There are usually several signs indicating the location of safety equipment in laboratories. These often have pictograms that indicate the use of the safety equipment.

know when and how to exit a laboratory safely and what first aid equipment is available. Since knowing how to handle laboratory emergencies is one of the "first things" that you need to learn about when working in chemistry laboratories, this is the content of Chapter 2.

The Student Safety Ethic

We conclude this introduction to safety with a key element to guide you in the undergraduate laboratory—*the student safety ethic*.[8] In Section 1.3.2 we will introduce the *the safety ethic*, which expands the *student safety ethic* to include a full range of topics for practicing chemists and researchers.

Ethics are principles of right or good conduct. When you work in the laboratory, it will be helpful to have a set of guiding principles relating to safety. Early on, we learn safety ethics from family members and teachers. In college, your instructors will teach about safety and encourage a safety ethic. Later in life, you will learn about safety from your employer, fellow employees, managers, and safety professionals in the workplace. Many employers have strong safety programs to protect their employees as well as their own financial interests and property. And since some employers may not emphasize safety, it is in these environments where your own safety ethic may be the most important or even challenged.

Why do you need strong safety ethics? People with weak safety ethics and a poor education in safety frequently put themselves at higher risks and are more likely to injure themselves or others. And beyond the workplace someday, you will want strong safety ethics to take care of your family and friends.

We encourage you to adopt the student safety ethic: *I work safely, avoid unnecessary risk, and accept responsibility for safety*.[8] This is a simple statement but it has broad implications and defines broad actions to implement (see Figure 1.1.1.4).

- To *work safely* means that you are educated in safety, you continue to learn about safety, you learn to recognize and evaluate hazards, you practice safe procedures, and you maintain a high level of safety awareness.
- To *avoid unnecessary risk* means that you learn to recognize risks and minimize and manage those risks when working in the laboratory.
- To *accept responsibility for safety* as an act of caring for others means that you are responsible and accountable for your safety and for the safety of others. This requires a constant awareness in