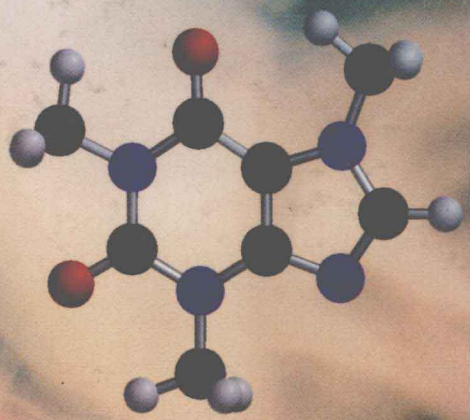
INTRODUCTION TO ORGANIC LABORATORY TECHNIQUES

A Microscale Approach

third edition



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Introduction to

Organic Laboratory Techniques

A Microscale Approach

Third Edition

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WARNINGS ABOUT SAFETY PRECAUTIONS

Some of the experiments contained in this Laboratory Manual involve a degree of risk on the part of the instructor and student. Although performing the experiments is generally safe for the college laboratory, unanticipated and potentially dangerous reactions are possible for a number of reasons, such as improper measurement or handling of chemicals, improper use of laboratory equipment, failure to follow laboratory safety procedures, and other causes. Neither the Publisher nor the Authors can accept any responsibility for personal injury or property damage resulting from the use of this publication.

Preface

In preparing this new edition of our microscale organic laboratory textbook, we have attempted to respond to the many helpful and constructive suggestions that we have received over the years. This edition, therefore, attempts to keep those features that have made our previous books as well-received as they have been, while adding new methods of teaching organic laboratory, with an eye to making the experiments more interesting and less routine than in previous editions.

NEW TO THIS EDITION

We have not included stand-alone technique experiments in previous editions of our textbooks. However, we are aware of many schools that use our textbook supplemented with their own technique experiments. Because of this and because our teaching philosophy has evolved over the past twenty years, we have included four new technique experiments in this book: *Crystallization, Extraction, Chromatography,* and *Distillation* (Experiments 3–6). We have also included an introductory experiment on solubility (Experiment 2), because solubility principles form the basis for several of the basic techniques. These five experiments emphasize understanding of and proficiency in performing the techniques. To further their understanding and to encourage students to think critically, we have included a number of "Critical Thinking Applications" at the end of several of these experiments. These are short exercises in which students must provide experimentally determined solutions to problems related to the techniques and the underlying principles.

For those of you who want to continue to teach techniques within the context of relevant experiments, we recommend that you skip the introductory technique experiments and use this book, starting with Experiment 7, in the same way that you used the Second Edition.

There is a new section in this textbook (Part 7) titled "Project-Based Experiments." In all of these experiments, students must either solve a significant problem or they must generate all or part of a procedure. These experiments are intended to require considerable critical thinking and to challenge the students. Some of these experiments will give students a feeling for research in chemistry.

New experiments, besides the introductory experiments in Part One, which have been added to this edition of the textbook include:

Experiment 17	Computational Chemistry
Experiment 55	A Separation and Purification Scheme
Experiment 56	Conversion of Cyclohexanol to Bromocyclohexane
Experiment 57B	Identification of the Constituents of Essential Oils by Gas Chromatography–Mass Spectrometry
Experiment 57C	Investigation of the Essential Oils of Herbs and Spices—A Mini-Research Project

Experiment 59	The Analysis of Antihistamine Drugs by Gas Chromatography-Mass Spectrometry
Experiment 60	The Aldehyde Enigma
Experiment 61	Michael and Aldol Condensation Reactions

The scale of most experiments is the same as it was in the Second Edition. In a number of experiments, we have included a semi-microscale procedure as an alternative to the microscale procedure. In the semi-microscale procedures, crystallizations are done in an Erlenmeyer flask rather than a Craig tube, and distillations are performed with conventional distillation equipment rather than a Hickman distillation head. For those of you not interested in using the alternative semi-microscale procedures, you will be pleased to know that all of the original microscale procedures have been retained. We have received feedback from some of you indicating that these semi-microscale procedures would be a desirable feature. We would appreciate receiving more feedback about this approach.

To make room for the new material which has been added, we had to delete a number of experiments which were in the previous edition. If we have deleted any of your favorite experiments, let us know and we'll take this into account when we write our next edition.

In this edition, we have updated the safety and waste disposal instructions that accompany each experiment. We recommend that virtually all waste, including aqueous solutions, be placed into appropriate waste containers. We have also made changes to improve the reliability of the experiments.

In a departure from many laboratory textbooks, we have included methods that bring the computer and the laboratory together. We have provided experiments that introduce students to molecular modeling and computational chemistry (Part 3). Optional exercises within some of the experiments allow students to apply these methods to their experiments.

We have also added gas chromatography-mass spectrometry (GC-MS) to the techniques section. There are also some new experiments that utilize GC-MS, and this combined method is described in a new section of the technique chapter on gas chromatography (Technique 15). There is also a new appendix which outlines some of the essential aspects of mass spectrometry (Appendix 6).

INSTRUCTOR'S MANUAL

We would like to call your attention to the Instructor's Manual that accompanies our textbook and is available from Saunders College Publishing or from your Saunders publisher's representative. The manual contains complete instructions for the preparation of reagents and equipment for each experiment, as well as answers to each of the questions. In some cases, additional optional experiments are included. Other comments that should prove helpful to the instructor include the estimated time to complete each experiment—and notes for special equipment or reagent handling. There is also a new section describing recommended waste management guidelines. We strongly recommend that instructors obtain a copy of this manual.

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If you wish to contact us with comments, questions, or suggestions, we have a special electronic mail address for this purpose (plke@chem.wwu.edu). We encourage you to visit our home page at http://atom.chem.wwu.edu/dept/plkhome.html. You may also wish to visit the Saunders College Publishing web site at http://www.saunderscollege.com.

Finally, we must thank our families and special friends, especially Neva-Jean Pavia, Marian Lampman, Carolyn Kriz, and Earl Engel, for their encouragement, support, and patience.

Donald L. Pavia
Gary M. Lampman
George S. Kriz
Randall G. Engel

November 1998

Contents

Part Six

Macroscale Experiments 469

Part Seven

Project-Based Experiments 481

Part Eight

The Techniques

Appendices A1

Index I1

Introduction

WELCOME TO ORGANIC CHEMISTRY!

Organic chemistry can be fun, and we hope to prove it to you. The organic chemistry laboratory, using microscale experiments, is also a pleasant place to work. This laboratory environment is cleaner and safer than traditional laboratories, and the level of skills that you will develop will be higher. The personal satisfaction that comes with performing a sophisticated experiment skillfully and successfully will be great.

To get the most out of the laboratory course, you should strive to do several things. First, you need to understand the organization of this laboratory manual and how to use the manual effectively. It is your guide to learning. Second, you must try to understand both the purpose and the principles behind each experiment you do. Third, you must try to organize your time effectively *before* each laboratory period.

Organization of the Textbook

Consider briefly how this textbook is organized. There are four introductory chapters, of which this Welcome is the first; a chapter on laboratory safety is second; advance preparation and laboratory records make up the third; and laboratory glassware is the fourth. Beyond these introductory chapters, the textbook is divided into eight parts. Part One contains six experiments that focus on developing some important basic laboratory techniques. Part Two contains nine experiments that introduce you to most of the essential techniques of microscale organic chemistry. We recommend that you perform all or most of the experiments in Parts One and Two. Part Three contains two experiments that introduce you to the modern, computer-based techniques of molecular modeling and computational chemistry. Part Four consists of 36 experiments that may be assigned as part of your laboratory course. Your instructor will choose a set of these experiments. Part Five is devoted to identifying organic compounds, and contains one experiment that provides experience in the analytical aspects of organic chemistry. Interspersed within these first five parts of the textbook are numerous covering essays that provide background information related to the experiments. Part Six contains three experiments intended to provide experience with important conventional-scale (macroscale) methods. These include conventional-scale filtration, crystallization, and extraction, plus use of a separatory funnel, simple distillation, and fractional distillation. There is also an essay that describes how to scale up a reaction. Part Seven collects eight experiments that require you to develop important critical thinking skills. Many of these experiments have a result that is not easily predicted in advance. To arrive at an appropriate conclusion, you will have to use many of the thought processes that are important in research. Part Eight consists of a series of detailed instructions and explanations dealing with the techniques of organic chemistry, with particular reference to microscale methods.

The techniques are extensively developed and used, and you will become familiar with them in the context of the experiments. Within each experiment, you will find a section, "Required Reading," that indicates which techniques you should study to do that experiment. Extensive cross-referencing to the techniques chapters in Part Eight is included in each experiment. Each experiment also contains a section called "Special Instructions," which lists special safety precautions and specific instructions to you the student. Finally, each experiment contains a section entitled "Waste Disposal," which provides instruction on the correct way to dispose of reagents and materials used during the experiment.

The Appendices to this textbook contain sections dealing with infrared spectroscopy, proton nuclear magnetic resonance, ^{13}C nuclear magnetic resonance, and mass spectrometry. Many of the experiments included in Parts One through Seven use these spectroscopic techniques, and your instructor may choose to add them to other experiments.

Advance Preparation

It is essential to plan carefully for each laboratory period so you can keep abreast of the material you will learn in your organic chemistry laboratory course. You should not treat these experiments as a novice cook would treat *The Good Housekeeping Cookbook.* You should come to the laboratory with a plan for the use of your time and some understanding of what you are about to do. A really good cook does not follow the recipe line-by-line with a finger, nor does a good mechanic fix your car with the instruction manual in one hand and a wrench in the other. In addition, you probably won't learn much if you follow the instructions blindly, without understanding them. We can't emphasize strongly enough that you should come to the lab *prepared.*

If there are items or techniques that you do not understand, do not hesitate to ask questions. You will learn more, however, if you figure things out on your own. Don't rely on others to do your thinking for you.

Read the chapter entitled "Advance Preparation and Laboratory Records" right away. Although your instructor will undoubtedly have a preferred format for keeping records, much of the material here will help you learn to think constructively about laboratory experiments in advance. It would also save time if, as soon as possible, you read the first six techniques chapters in Part Eight. These techniques are basic to all experiments in this textbook. You should also read the experiment "Introduction to Microscale Laboratory," on pp. 38–49. The laboratory class will begin with experiments almost immediately, and a thorough familiarity with this particular material will save you much valuable laboratory time.

It is also very important to read the chapter called "Laboratory Safety." It is your responsibility to know how to perform the experiments safely and how to understand and evaluate risks associated with laboratory experiments. Knowing what to do and what not to do in the laboratory is of paramount importance, because the laboratory has many potential hazards.

Budgeting Time

As mentioned in the "Advance Preparation" section of this chapter, you should read several chapters of this book even before your first laboratory class meeting. You should also read the assigned experiment carefully before every class meeting. Having read the experiment will help you schedule your time wisely. Often you will be doing more than one experiment at a time. Experiments such as the fermentation of sugar or the chiral reduction of ethyl acetoacetate require a few minutes of advance preparation *one week* ahead of the actual experiment. At other times you will have to catch up on some unfinished details of a previous experiment. For instance, usually it is not possible to determine a yield accurately or a melting point of a product immediately after you first obtain the product. Products must be free of solvent to give an accurate weight or melting point range; they must be "dried." Usually this drying is done by leaving the product in an open container on your desk or in your locker. Then, when you have a pause in your schedule during the subsequent experiment, you can determine these missing data using a dry sample. Through careful planning you can set aside the time required to perform these miscellaneous experimental details.

The Purpose

The main purpose of an organic laboratory course is to teach you the techniques necessary for dealing with organic chemicals. You will learn how to handle equipment that is becoming increasingly common in many laboratories. You will also learn the techniques needed

for separating and purifying organic compounds. If the appropriate experiments are included in your course, you may also learn how to identify unknown compounds. The experiments themselves are only the vehicle for learning these techniques. The technique chapters in Part Eight are the heart of this textbook, and you should learn these techniques thoroughly. Your instructor may provide laboratory lectures and demonstrations explaining the techniques, but the burden is on you to master them by familiarizing yourself with these chapters.

Besides good laboratory technique and the methods of carrying out basic laboratory procedures, you will also learn from this laboratory course how to

1. Work safely
2. Take data carefully
3. Record relevant observations
4. Use your time effectively
5. Assess the efficiency of your experimental method
6. Plan for the isolation and purification of the substance you prepare
7. Solve problems and think like a chemist

In choosing experiments, we have tried whenever possible to make them relevant, and, more importantly, interesting. To that end, we have tried to make them a learning experience of a different kind. Most experiments are prefaced by a background essay to place things in context and to provide you with some new information. We hope to show you that organic chemistry pervades your lives (in drugs, foods, plastics, perfumes, and so on). Furthermore, you should leave your course well-trained in organic laboratory techniques. We are enthusiastic about our laboratory course, and hope you will be, too.

LABORATORY SAFETY

In any laboratory course, familiarity with the fundamentals of laboratory safety is critical. Any chemistry laboratory, particularly an organic chemistry laboratory, can be a dangerous place in which to work. Understanding potential hazards will serve well in minimizing that danger for you. We have pointed out specific hazards in the experiments found in this textbook. However, it is ultimately your responsibility, along with the laboratory instructor, to make sure that all laboratory work is carried out in a safe manner.

Safety Guidelines

The introduction of microscale techniques has significantly reduced many dangers found in organic laboratories; however, you still must take many precautions. Your laboratory instructor will advise you of specific rules for your laboratory. The following list of safety guidelines should be observed in all organic laboratories.

1. Eye Safety

Always Wear Approved Safety Glasses or Goggles. This sort of eye protection must be worn whenever you are in the laboratory. Even if you are not actually carrying out an experiment, a person near you might have an accident that could endanger your eyes, so eye protection is essential. Even dish washing may be hazardous. We know of cases in which a person has been cleaning glassware only to have an undetected piece of reactive material explode, throwing fragments into the person's eyes. To avoid such accidents, wear your safety glasses at all times.

Learn the Location of Eyewash Facilities. If there are eyewash fountains in your laboratory, determine which one is nearest to you before your start to work. In case any chemical enters your eyes, go immediately to the eyewash fountain and flush your eyes and face with large amounts of water. If an eyewash fountain is not available, the laboratory will usually have at least one sink fitted with a piece of flexible hose. When the water is turned on, this hose can be aimed upward and directly into the face, working much like an eyewash fountain. To avoid damaging the eyes, the water flow rate should not be set too high, and the temperature should be slightly warm.

2. Fires

Use Care with Open Flames in the Laboratory. Because an organic chemistry laboratory course deals with flammable organic solvents, the danger of fire is frequently present. Because of this danger, DO NOT SMOKE IN THE LABORATORY. Furthermore, use extreme caution when you light matches or use any open flame. Always check to see whether your neighbors on either side, across the bench, and behind you are using flammable solvents. If so, either delay your use of a flame or move to a safe location, such as a fume hood, to use your open flame. Many flammable organic substances are the source of dense vapors that can travel for some distance down a bench. These vapors present a fire danger, and you should be careful, because the source of those vapors may be far away from you. Do not use the bench sinks to dispose of flammable solvents. If your bench has a trough running along it, pour only *water* (no flammable solvents!) into it. The troughs and sinks are designed to carry water—not flammable materials—from the condenser hoses and aspirators.

Learn the Location of Fire Extinguishers, Fire Showers, and Fire Blankets. For your own protection in case of a fire, you should learn immediately where the nearest fire extinguisher, fire shower, and fire blanket are. You should learn how these safety devices are operated, particularly the fire extinguisher. Your instructor can demonstrate how to operate it.

If you have a fire, the best advice is to get away from it and let the instructor or laboratory assistant take care of it. DON'T PANIC! Time spent in thought before action is never wasted. If it is a small fire in a container, it usually can be extinguished quickly by placing a wire gauze screen with a ceramic fiber center or, possibly, a watch glass, over the mouth of the container. It is good practice to have a wire screen or watch glass handy whenever you are using a flame. If this method does not take care of the fire and if help from an experienced person is not readily available, then extinguish the fire yourself with a fire extinguisher.

Should your clothing catch on fire, DO NOT RUN. Walk *purposefully* toward the fire shower station or the nearest fire blanket. Running will fan the flames and intensify them.

3. Organic Solvents: Their Hazards

Avoid Contact with Organic Solvents. It is essential to remember that most organic solvents are **flammable** and will burn if they are exposed to an open flame or a match. Remember also that on repeated or excessive exposure, some may be toxic or carcinogenic (cancer causing) or both. For example, many chlorocarbon solvents, when accumulated in the body, cause liver deterioration similar to cirrhosis caused by excessive use of ethanol. The body does not rid itself easily of chlorocarbons nor does it **detoxify** them; they build up over time and may cause illness in the future. Some chlorocarbons are also suspected to be carcinogens. MINIMIZE YOUR EXPOSURE. Long-term exposure to benzene may cause a form of leukemia. Don't sniff benzene, and avoid spilling it on yourself. Many other solvents, such as chloroform and ether, are good anesthetics and will put you to