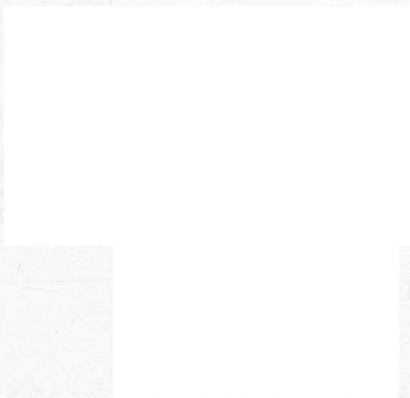


EXPERIMENTAL ORGANIC CHEMISTRY

DANIEL R. PALLEROS

University of California, Santa Cruz



JOHN WILEY & SONS, INC.

New York ■ Chichester ■ Weinheim ■ Brisbane ■ Toronto ■ Singapore

828580

All experiments contained herein have been performed several times by students in college laboratories under supervision of the author. If performed with the materials and equipment specified in this text, in accordance with the methods developed in this text, the author believes the experiments to be safe and valuable educational experience. However, all duplication or performance of these experiments is conducted at one's own risk. The author does not warrant or guarantee the safety of individuals performing these experiments. This text provides basic guidelines for safe practices and waste disposal in the undergraduate organic chemistry laboratory. It cannot be assumed that all necessary warning and precautionary measures are contained in this text, or that other or additional information or measures may not be required. Since local, state, and federal regulations regarding the disposal of waste are subject to change, such regulations should be checked by the schools before following the clean-up procedures mentioned in this text. The author hereby disclaims any liability for any loss or damage claimed to have resulted from or been related in any way to the experiments, regardless of the form of action.

ACQUISITIONS EDITOR	Jennifer Yee
SENIOR PRODUCTION EDITOR	Elizabeth Swain
SENIOR MARKETING MANAGER	Charity Robey
SENIOR DESIGNER	Karin Gerdes Kincheloe
ILLUSTRATION EDITORS	Sandra Rigby and Edward Starr
PHOTO EDITOR	Lisa Gee
COVER PHOTO	Paul Schraub
COVER CONCEPT	Daniel R. Palleros
ILLUSTRATIONS	Fine Line Illustrations, Inc.

This book was set in 10/12 Palatino Light by Laser Words and printed and bound by Courier/Westford. The cover was printed by Lehigh.

This book is printed on acid-free paper. ∞

Copyright © 2000 John Wiley & Sons, Inc. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012, (212) 850-6011, fax (212) 850-6008, E-Mail: PERMREQ@WILEY.COM.

To order books or for customer service, call 1(800)-CALL-WILEY (225-5945).

Library of Congress Cataloging in Publication Data:

Palleros, Daniel R.

Experimental organic chemistry / Daniel R. Palleros.
p. cm.

Includes bibliographical references and index.

ISBN 0-471-28250-2 (cloth : alk. paper)

1. Chemistry, Organic Laboratory manuals. I. Title.

QD261.P335 1999

99-35417

547.078-dc21

CIP

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

062938

20062938

Experimental Organic Chemistry

B)

DANIEL R. PALLEROS

University of California, Santa Cruz



JOHN WILEY & SONS, INC.

New York ■ Chichester ■ Weinheim ■ Brisbane ■ Toronto ■ Singapore

To my students

Contents

SECTION I

THE BASICS

1

Unit 1 Laboratory Safety

3

1.1 General Safety Guidelines 3

1.2 Chemical Toxicity 4

1.3 Dealing with Chemicals and Waste Disposal 7

1.4 Online Safety Resources 15

Unit 2 Basic Concepts

19

2.1 Polarity and H-Bonds 19

2.2 Physical Data 21

2.3 Solvents 24

2.4 Balancing Chemical Equations 26

2.5 Concentration Units 28

2.6 Moles and Millimoles 29

2.7 Neutral Acids 31

2.8 Calculation of yields 31

2.9 Scaling Up, Scaling Down 34

2.10 Keeping Lab Books and Writing Lab Reports 34

2.11 Chemical Laboratory 35

Unit 3 Basic Operations

45

3.1 Handling Liquids 45

3.2 Weighing 46

3.3 Titration 47

3.4 Filtering 51

3.5 Evaporation 53

3.6 Centrifugation 55

3.7 Caring for Glassware 56

3.8 Measuring Pressure 57

Preface

To the Students

You are about to embark in what may be a life-changing experience. After taking organic chemistry, a stroll in the forest will never be the same. You will perceive the world around you with renewed senses as if a new dimension had been added. This dimension is knowledge.

Organic chemistry is everywhere, from the delicate smell of violets to the paper these words are printed on. In the organic chemistry laboratory you will learn to decode some of nature's secrets, and in doing so, you will learn to use tools that will extend your senses to the molecular level. You will also learn a new language that will enable you to describe what you see through the magnifying glass of experimental organic chemistry.

In the laboratory you will learn to observe, interpret, and predict organic chemistry. You will develop your problem-solving skills and will gain a sense of self-confidence and self-reliance. By the end of this course you will be proficient in the most important aspects of laboratory work and will be able to design and interpret your own experiments.

In developing this laboratory course I tried to be loyal to my conviction that we learn only what we enjoy. Whenever possible, I made an effort to relate the experiments to everyday life and to provide social and historical notes. Many of the experiments have biological applications or are connected to medicine. For example, you will prepare diiodotyrosine, a compound related to the thyroid hormones that control metabolism and development. You will transform a pain-relief ointment, such as Bengay, into aspirin. You will isolate caffeine from tea. You will analyze vitamin tablets. You will isolate the components of milk. You will prepare fragrances that mimic the smell of fruits and flowers. You will obtain volatile oils from plants. You will make an ant pheromone (pheromones are compounds used by animals to communicate with members of the same species). You will explore the chemistry of steroids. You will make plastics and dye fabrics.

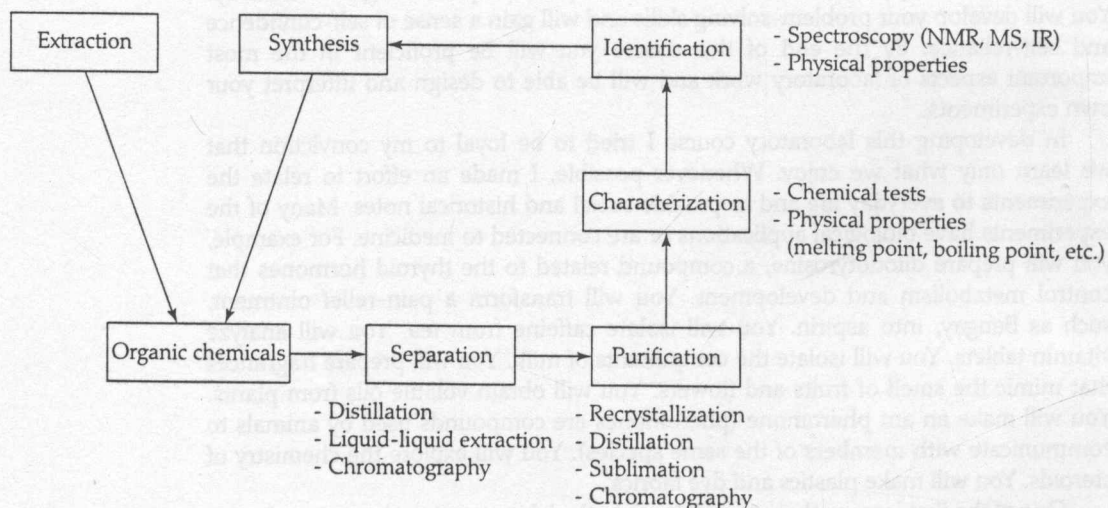
One of the first lessons that you will learn in the laboratory is to be patient. In this fast-paced society it seems that patience is a virtue that has fallen by the wayside. As a scientist in-training you will learn to follow nature at its own speed and to respect its timing. Very often, there is little we can do to hasten the course of an experiment. In the laboratory you will learn to budget your time efficiently while waiting for an experiment to conclude. You will also learn to take frustration in stride. An experiment may not work as planned and must be repeated. But a failed experiment gives us an opportunity to learn from our mistakes. Another lesson you will learn in the laboratory is to be faithful to your data. You will learn to accept your results and treat them with respect, avoiding embellishment and intentional omissions. Remember that the building of science is made of truth and its foundations are rooted in trust. It is in the

laboratory where the advances of science are made. Without laboratory work, science would be just a poetic fabrication.

You are not alone in the endeavor of discovering experimental organic chemistry. All of us working in the laboratory, from the beginner to the most seasoned chemist, are always learning new aspects of this science, art, and craft.

The Subject of Experimental Organic Chemistry

In this course you will learn to work with organic chemicals by obtaining them, identifying them, and transforming them. Organic chemicals can either be obtained from natural sources, by a technique called *extraction*, or can be prepared from other chemicals by a technique called *synthesis*. When a compound is extracted from nature or synthesized in the laboratory, it is hardly ever obtained in a pure form. Normally the chemical of interest is in a mixture with other components from which it must be separated. After the *separation*, the chemist must make sure that residual amounts of the other components, called impurities, are eliminated from the compound of interest. This process is called *purification*. Separation and purification are carried out by similar techniques (see diagram below), and the differences between the two procedures are more conceptual than operational. In the separation of a mixture, the chemist usually recovers all of its components in separate containers. In the purification of a chemical, on the other hand, the chemist is only interested in that chemical and tosses away the impurities. In this course you will learn many separation and purification techniques such as recrystallization, distillation, chromatography in all of its different forms (gas chromatography, thin-layer chromatography, column chromatography, and high-performance liquid chromatography), sublimation, liquid-liquid extraction, and acid-base extraction. Units 4–10 and 14 are devoted to these subjects.



After a compound has been purified, it must be characterized and identified. *Characterization* and *identification* go hand in hand and are performed by similar techniques. Characterization, which usually precedes identification, is the study of the physical and chemical properties of a compound. Characterization is done by chemical tests, which by a simple color change in a test tube can give valuable information about the chemical, and also by the determination of physical properties such as melting point, boiling point, refractive index, and density. Identification, on the other hand, is a more involved procedure and implies the elucidation of the structure of the compound. Identification is normally accomplished by a battery of chemical and

spectroscopic methods. Nuclear magnetic resonance (NMR), infrared spectroscopy (IR), and mass spectrometry (MS) are among the most valuable tools to this end. You will find numerous spectroscopic applications at the end of the experiments beginning in Unit 11. Units 30–34 are fully devoted to spectroscopy.

Organization

This book is organized into three sections. **Section 1** (The Basics) contains three units: Laboratory Safety (Unit 1), Basic Concepts (Unit 2), and Basic Operations (Unit 3). Read Unit 1 and familiarize yourself with the safe practices in the laboratory *before* you start your experimental work. You can delay reading Unit 2 and Unit 3 until a later time if you want. These units contain basic information about common operations and procedures in the laboratory. Some of this information is a review of what you have already learned in general chemistry; other information will be new to you. You will find references to Units 2 and 3 throughout the book.

Section 2 (Units 4–29) contains the experiments. Each unit is composed of two parts: the background information and the experiments themselves. There are exercises at the end of each background part with answers to selected problems at the end of the book. Try to work out these problems; they will give you a deeper understanding of the subject and will prepare you to do and enjoy the experiments. Interlaced in these exercises you will find the story of Synton X. Plosiff, a “slightly vain, somewhat absent-minded, but totally dedicated graduate student” who is our fictional chemistry hero. I hope that you like him and his friends.

Each experiment begins with an overview where you will find a brief description of the aims and organization of the experiment. Read this part carefully because it will provide you with the “big picture” of the experiment. At the end of each experimental part you will find guidelines, in the form of **pre-lab** and **in-lab questions**, to help you prepare for the experiment and write a lab report. Answer the pre-lab questions before you start your experimental work. They will help you understand and take full advantage of the experiment. The in-lab questions will assist you in interpreting and analyzing your data.

Section 3 (Units 30–34) deals with spectroscopy: infrared (Unit 31), ultraviolet-visible (UV-vis, Unit 32), nuclear magnetic resonance (Unit 33), and mass spectrometry (Unit 34). All of the spectroscopic techniques are grouped together in one section because they are routinely used in most of the experiments. You should read the spectroscopy units as the course progresses according to the needs of the experiments or as indicated by your instructor.

To the Instructors

One of my main goals in writing this book was to acknowledge that chemistry, like music, can only be learned in a progressive manner. Basic laboratory techniques should be learned and practiced before they can be properly put to use to explore more advanced problems. The experiments in Units 4–11 and 14 introduce the most important techniques in the organic chemistry laboratory through extensive practice. Recrystallization, distillation, extraction, and chromatography are among the techniques presented in these units. The treatment of these techniques is thorough from both a theoretical and a practical standpoint.

The units in this book are modular and do not need to be introduced in the order in which they are presented. However, I have found that students understand the concept of chromatography better if the subject is presented after liquid-liquid extraction and if a connection between partitioning between two liquid phases and partition chromatography is made. Also, high-performance liquid chromatography is better appreciated by the students if they have a previous knowledge of gas chromatography.

In general, two experiments, or one experiment with several independent parts, are offered in each unit. The teachers can select the parts that suit their needs. To

help focus the students, the suggested background reading is listed at the beginning of each experiment.

Beginning in Unit 12, experiments on the chemistry of functional groups are introduced in an order similar to that in which most organic chemistry textbooks present them. However, these units are also modular and teachers can alter this order without important consequences. The background information on the chemistry of functional groups summarizes only the most important aspects of their chemistry, with emphasis on experimental issues.

Unit 18 covers the subject of chemical kinetics and reaction mechanisms. The principles of kinetics are also illustrated in Units 19 and 29. In these experiments the students will go beyond the determination of rate constants and will learn to use chemical kinetics as a tool for the elucidation of reaction mechanisms. Unit 21 is about oxidation and reduction reactions. Grouping these subjects in one unit enables students to compare different methods and see their applications and limitations. Unit 23 deals with multistep synthesis. With a few exceptions, organic synthesis as a subject in its own right is not discussed in introductory lecture textbooks. Given the growing importance of this subject, a discussion of the concepts of retrosynthesis and synthons is presented in this unit. Units 26 and 27 deal with the chemistry of polymers and dyes. Both units provide a wide range of experiments to choose from. Unit 28, on bioorganic chemistry, introduces students to the use of microorganisms to perform stereospecific transformations.

The units on spectroscopy (Units 30–34) are intended to be used as the course progresses. From Experiment 11 on, most experiments include spectroscopic analysis. If the instrumentation is available, the students should obtain their own spectra. State-of-the-art IR, ^1H -NMR, and ^{13}C -NMR, and sometimes the mass spectra, are provided in this book for comparison and interpretation. It is up to the teacher to decide how much use they want to make of spectroscopic techniques. The treatment of IR and NMR includes a discussion of the technique of Fourier transform. Despite its growing use and importance, this subject is only tangentially treated in most textbooks. I tried to remedy this situation by providing a discussion that can be followed by students without much background in physics and math. Extensive sets of correlation tables are offered for UV-visible, IR, MS, and, especially, NMR.

There has been a major change in the teaching of experimental organic chemistry in the last 10 years. The widespread use of microscale experiments brought about by the work of D. Mayo, R. Pike, and S. Butcher in 1986 (*Microscale Organic Laboratory*, Wiley, New York) has revolutionized the way in which experimental organic chemistry is taught. Although the advantages offered by the microscale approach are many, I feel that students should also learn the macroscale approach because, out of necessity, in academia as well as in industry, some chemical operations are performed at the macroscale level. This book offers both approaches, especially when general laboratory techniques such as distillation, recrystallization, and extraction are introduced. Most of the syntheses, however, are at the micro or semi-micro level. By the end of the course the students should be in a position to decide at which scale an experiment would be best performed.

The experiments presented in this book emphasize the importance of critical thinking through extensive practice in problem solving and chemical analysis. The pre-lab and in-lab questions are designed to make the students actively participate in the experiments. In many of the experiments, the students will analyze and identify unknown samples. To this end they will make use of different techniques such as melting point, gas chromatography, thin-layer chromatography, polarimetry, refractive index, preparation of derivatives, and infrared and nuclear magnetic resonance spectroscopies. Many experiments have open-ended questions; others are puzzles for the students to solve. For example, Experiment 12 covers an investigation of the main product of a dehydration reaction; Experiment 16B involves a puzzle in electrophilic aromatic substitution; Experiment 18 covers the study of the kinetics and mechanism

of a nucleophilic aromatic substitution reaction; Experiment 19B involves the study of the hydrophobic effect in the Diels-Alder reaction; Experiment 20A explores the identification of carbonyl compounds; Experiment 21 includes the identification of a reduction product; Experiment 23B shows the synthesis and identification of ionones; and Experiment 28 involves the study of a reduction pathway mediated by yeast, which also includes NMR conformational analysis.

The experiments have been designed to be performed by each student individually. I believe that in the organic chemistry laboratory the students should develop a sense of self-confidence in their practical skills that can only be obtained by working independently. I also believe that students, as scientists in-training, should learn to share results. Some experiments are designed so students can team up to investigate different parts of a larger problem. They still work individually, but they need to consult each other along the way and share their results in order to bring the experiment to a conclusion.

"Safety First" boxes are incorporated at the beginning of each experiment. They highlight the most important hazards in dealing with the chemicals. However, they are not a substitute for the Material Safety Data Sheets, which should be made available to the students in the laboratory. **"Cleaning up"** guidelines are offered at the end of each experiment. They will help in the collection, segregation, and disposal of the waste. Because waste disposal procedures vary locally, these guidelines should be checked by laboratory personnel against local and state regulations before disposing of any chemical, or before instructing the students to do so.

All the experiments presented in this book have been tried and optimized in our teaching laboratories. They work as planned under the conditions described here. Suggestions and comments are welcome and will help us in future editions.

Acknowledgments

No book is the work of just one person. Many people helped me at different stages in the production of this book, and to all of them I am grateful. I cannot list the thousands of students who used this book in its preliminary format and who were instrumental in refining the experiments presented here, but I am indebted to all of them, and to all of them this work is dedicated. I am also grateful to my teaching assistants who were always on the lookout for ways to improve the experimental procedures. Particular thanks go to Kris Kessler for her constant help and technical support, to Keith Oberg who carefully read the early stages of the manuscript, to Monika Hennig and Alvin Go for their patience in proofreading the text, to Jim Loo for his enthusiastic technical support in obtaining the NMR spectra, to Mary Howe for her help with the mass spectra, to Lori Nicholson, Beau Willis, Barbara Klipfel, Buddy Morris, Dan Blunk, and Bob Bailey for their assistance with waste disposal and safety matters, to Linda Locatelli for sharing her expertise in plants and seeds with me, and to Micheline Markey for her artistic talents in obtaining some of the photographs shown here.

I am especially indebted to the people at Wiley: Jennifer Yee, my Editor, who patiently and skillfully directed the entire project, Nedah Rose who believed in this project from the beginning, Elizabeth Swain, Senior Production Editor, who carefully managed the metamorphosis of the manuscript into this book, Lisa Gee who researched the sources of many of the photographs, Sandra Rigby who coordinated the rendering of the artwork, and Karin Gerdes Kincheloe who designed the cover. I would also like to thank the reviewers of the manuscript for their comments and suggestions, among them Jared A. Butcher (Ohio University), Clifford W. J. Chang (University of West Florida), Craig Fryhle (Pacific Lutheran University), Ronald Lawler (Brown University), Michael F. McCormick (Emory University), J. Ty Redd (Southern Utah University), L. Kraig Steffen (Fairfield University), and Robert D. Walkup (Texas Tech University). I would also like to thank all of my colleagues at UCSC for their

constant support. I am particularly grateful to Professors Joseph Bunnett and Anthony Fink for their encouragement. Finally, I would like to acknowledge my friends from the University of Buenos Aires, School of Exact and Natural Sciences, for their inspiration, especially my dear friend Susi Socolovsky for her unfailing support over the years.

DANIEL R. PALLEROS
Santa Cruz, California

Contents

SECTION 1

THE BASICS

1

Unit 1 Laboratory Safety

3

- 1.1 General Safety Guidelines, 3
- 1.2 Chemical Toxicity, 6
- 1.3 Dealing with Chemicals and Waste Disposal, 7
- 1.4 Online Safety Resources, 15

Unit 2 Basic Concepts

19

- 2.1 Polarity and H-Bonds, 19
- 2.2 Physical Data, 23
- 2.3 Solvents, 24
- 2.4 Balancing Chemical Equations, 26
- 2.5 Concentration Units, 28
- 2.6 Moles and Millimoles, 29
- 2.7 Mineral Acids, 31
- 2.8 Calculation of Yields, 32
- 2.9 Scaling Up, Scaling Down, 34
- 2.10 Keeping Lab Books and Writing Lab Reports, 34
- 2.11 Chemical Literature, 35

Unit 3 Basic Operations

45

- 3.1 Handling Liquids, 45
- 3.2 Heating, 46
- 3.3 Filtration, 47
- 3.4 Refluxing, 51
- 3.5 Evaporation, 53
- 3.6 Centrifugation, 55
- 3.7 Caring for Glassware, 55
- 3.8 Measuring Pressure, 57

SECTION 2**THE EXPERIMENTS****59****Unit 4 Recrystallization and Melting Point****61**

- 4.1 Overview, 61
- 4.2 Recrystallization, 62
- 4.3 Decolorizing Charcoal, 69
- 4.4 Recrystallization from Mixed Solvents, 70
- 4.5 Microscale Recrystallization, 70
- 4.6 Melting Point, 71
- 4.7 Sublimation, 75

Experiment 4 Recrystallization of Acetanilide and Urea**79**

- E4.1 Recrystallization of Acetanilide, 80
- E4.2 Microscale Recrystallization of Urea, 82
- E4.3 Determination of Melting Points, 82

Unit 5 Extraction**86**

- 5.1 Introduction, 86
- 5.2 Solvent-Solvent Partitioning, 86
- 5.3 Macroscale Liquid-Liquid Extraction, 92
- 5.4 Microscale Liquid-Liquid Extraction, 93
- 5.5 Drying the Organic Layer, 94
- 5.6 Solid-Liquid Extraction, 95
- 5.7 Countercurrent Distribution, 97

Experiment 5 Isolation of Caffeine from Tea**103**

- E5.1 Tea, Coffee, and Caffeine, 103
- E5.2 Caffeine from Tea: Overview of the Experiment, 105
- E5.3 Isolation of Caffeine, 109
- E5.4 Purification of Caffeine by Sublimation, 110
- E5.5 Purification of Caffeine by Recrystallization (Alternative Procedure), 111

Unit 6 Distillation — Separation and Purification of Organic Liquids**113**

- 6.1 Boiling Point, 113
- 6.2 Boiling Point and Molecular Structure, 114
- 6.3 Simple Distillation, 115
- 6.4 Fractional Distillation, 120
- 6.5 Ideal and Nonideal Solutions, 123
- 6.6 Azeotropic Mixtures, 124
- 6.7 Fractionating Columns, 125
- 6.8 Microscale Distillation, 126
- 6.9 Boiling Point Determination, 128
- 6.10 Vacuum Distillation, 129
- 6.11 Steam Distillation, 130

Experiment 6A Distillation of Alcohols**136**

- E6A.1 Distillation of Methanol from a Mixture with Ferric Chloride, 136
- E6A.2 Separation of Methanol-Water by Simple Distillation, 137
- E6A.3 Separation of Methanol-Water by Fractional Distillation, 138
- E6A.4 Analysis of the Distillation Fractions by Density, 139

<i>Experiment 6B Isolation of Anise Oil</i>	142
E6B.1 Overview, 142	
E6B.2 Isolation of Anise Oil, 142	
Unit 7 Gas Chromatography	144
7.1 Introduction, 144	
7.2 The Chromatographic Methods, 144	
7.3 Partition Chromatography, 146	
7.4 Gas Chromatography, 149	
7.5 The Gas Chromatograph, 151	
7.6 Measuring the Retention Time, 155	
7.7 Integration, 156	
7.8 Quantitative Analysis, 157	
7.9 Quantitative Analysis: A Closer Look (Advanced Level), 158	
7.10 Qualitative Analysis, 161	
7.11 Running GC: Step by Step, 162	
7.12 Gas Chromatography Do's and Don'ts, 163	
<i>Experiment 7A Gas Chromatography of Alcohols</i>	167
E7A.1 Analysis of Alcohols, 167	
E7A.2 Separation of Methanol and Water, 168	
<i>Experiment 7B Analysis of Anise Oil</i>	170
E7B Analysis of Anise Oil, 170	
Unit 8 Thin-Layer Chromatography	172
8.1 Overview, 172	
8.2 The Adsorption Process, 173	
8.3 Selection of TLC Conditions, 175	
8.4 Running TLC Plates, 178	
8.5 Adsorption Isotherms (Advanced Level), 182	
8.6 Applications of TLC, 184	
8.7 Other Stationary Phases, 186	
8.8 TLC Do's and Don'ts, 186	
<i>Experiment 8 TLC Analysis of Vegetable Extracts</i>	190
E8.1 Plant Pigments, 190	
E8.2 Isolation and Analysis of Plant Pigments, 192	
Unit 9 Column Chromatography	197
9.1 Overview, 197	
9.2 Practical Aspects, 197	
9.3 Applications, 202	
9.4 Column Chromatography Do's and Don'ts, 203	
<i>Experiment 9 Isolation of C₆₀ from Fullerene Soot</i>	206
E9.1 Fullerenes, 206	
E9.2 Isolation of Fullerenes, 207	
E9.3 A Chemical Test for Fullerenes, 208	
E9.4 Overview of the Experiment, 209	
E9.5 Isolation of C ₆₀ from Fullerene Soot, 209	
Unit 10 High-Performance Liquid Chromatography	214
10.1 Overview, 214	
10.2 HPLC Systems, 214	

- 10.3 HPLC Versus GC, 215
- 10.4 Solvents, 216
- 10.5 Pumps, 217
- 10.6 Injection Port, 217
- 10.7 Columns, 218
- 10.8 Detectors, 219
- 10.9 Why is HPLC High Performance?, 220
- 10.10 Reversed-Phase Chromatography, 221
- 10.11 Other Chemically Bonded Stationary Phases, 222
- 10.12 Size-Exclusion Chromatography, 223
- 10.13 Quantitative Determinations: Standard Curve Method, 224
- 10.14 HPLC Do's and Don'ts, 224

Experiment 10 Vitamin Analysis — A Quantitative Study

227

- E10.1 Water-Soluble and Fat-Soluble Vitamins, 227
- E10.2 Vitamin Stability, 229
- E10.3 International Units, 230
- E10.4 Characterization of Vitamin A, 230
- E10.5 Overview of the Experiment, 231

Unit 11 Refractometry and Polarimetry

238

- 11.1 Refractive Index, 238
- 11.2 The Refractometer, 239
- 11.3 Measuring the Refractive Index, 240
- 11.4 Polarimetry, 242
- 11.5 The Polarimeter, 245
- 11.6 Measuring the Optical Rotation, 246
- 11.7 Optical Rotation of Mixtures, 247

Experiment 11A Analysis of Essential Oils

250

- E11A.1 Terpenoids, 250
- E11A.2 Essential Oils, 252
- E11A.3 Specific Rotation, 253
- E11A.4 Refractive Index, 253
- E11A.5 Composition of Essential Oils, 253

Experiment 11B Separation of Carvone and Limonene

255

- E11B.1 Carvone and Limonene, 255
- E11B.2 Analysis of the Crude Oils, 256
- E11B.3 Separation of Carvone and Limonene, 257

Unit 12 Alcohols and Alkenes

261

- 12.1 Alkenes from Alcohols, 261
- 12.2 Dehydration Mechanisms, 262
- 12.3 Characterization of Alkenes, 264

Experiment 12 The Dehydration of Methylcyclohexanols

268

- E12.1 Overview, 268
- E12.2 Dehydration of Methylcyclohexanols, 269
- E12.3 Analysis of the Product Mixture, 270

Unit 13 Alkyl Halides

273

- 13.1 Preparation, 273
- 13.2 Reactions, 274

13.3 Alkyl Halides from Alcohols, 274

13.4 Characterization Tests, 276

Experiment 13 Synthesis of *n*-Butyl Bromide and 2-Chloro-2-Methylbutane

280

E13.1 Synthesis of *n*-Butyl Bromide, 280

E13.2 Synthesis of 2-Chloro-2-Methylbutane, 284

E13.3 Characterization Tests, 285

Unit 14 Acid-Base Extraction

292

14.1 Introduction, 292

14.2 Acids and Bases, 292

14.3 Structural Effects on Acid-Base Properties, 294

14.4 Acid-Base Extraction, 298

14.5 Overview, 303

Experiment 14A Isolation of Eugenol from Cloves

307

E14A.1 Ancient Medicine, 307

E14A.2 Eugenol from Cloves: Overview of the Experiment, 307

E14A.3 Isolation of Eugenol, 308

E14A.4 GC and IR Analyses, 310

Experiment 14B Isolation of the Active Ingredients in an Analgesic Tablet

315

E14B.1 Overview, 315

E14B.2 Separation of the Active Ingredients in Excedrin, 317

E14B.3 Analysis, 317

Unit 15 Phenols and Ethers

323

15.1 Phenols and Ethers, 323

15.2 Williamson Ether Synthesis, 323

15.3 Characterization of Phenols: Ferric Chloride Test, 324

15.4 IR and NMR of Phenols and Ethers, 325

Experiment 15 Medicinal Chemistry: From Tylenol to a Banned Chemical

327

E15.1 Analgesics, 327

E15.2 The Experiment: Overview, 329

E15.3 Conversion of Acetaminophen into Phenacetin, 330

E15.4 Ferric Chloride Test, 332

E15.5 Analysis of Analgesics by TLC, 332

Unit 16 Electrophilic Aromatic Substitution

336

16.1 Mechanism of Electrophilic Aromatic Substitution, 336

16.2 Nitration and Halogenation, 337

16.3 Effects of Substituents, 338

Experiment 16A Iodination of Tyrosine

342

E16A.1 Synthesis of 3,5-Diiodotyrosine, 342

Experiment 16B Two Substitution Puzzles

350

E16B.1 Overview, 350

E16B.2 NMR Analysis, 351

E16B.3 Nitration of Phenacetin, 352

E16B.4 Bromination of Phenacetin, 353

Unit 17 Nucleophilic Aromatic Substitution	355
17.1 Nucleophilic Aromatic Substitution, 355	
17.2 Dinitroanilines, 356	
<i>Experiment 17 Dinitrocompounds—Herbicides</i>	360
E17.1 Synthesis of Trifluralin, 360	
E17.2 Synthesis of <i>N</i> -(<i>n</i> -Butyl)-2,4-Dinitroaniline, 361	
E17.3 Herbicide Effects of Trifluralin and <i>N</i> -(<i>n</i> -Butyl)-2,4-Dinitroaniline, 362	
Unit 18 Chemical Kinetics	368
18.1 Mechanistic Studies, 368	
18.2 Chemical Kinetics, 368	
18.3 Experimental Aspects, 370	
18.4 Integrated Rate Equations, 370	
18.5 Reaction Half-Life, 372	
18.6 Transition States, 372	
18.7 Dependence of the Rate Constant with Temperature: Arrhenius Equation, 375	
18.8 Following the Kinetics, 375	
18.9 Best Fit, 377	
<i>Experiment 18 Nucleophilic Aromatic Substitution Kinetics</i>	381
E18.1 The Problem, 381	
E18.2 To Follow the Kinetics, 383	
E18.3 Overview of the Experiment, 383	
E18.4 Synthesis of 2,4-Dinitroanisole, 384	
E18.5 Visible Spectrum of <i>N</i> -(<i>n</i> -Butyl)-2,4-Dinitroaniline, 384	
E18.6 Beer's Law of <i>N</i> -(<i>n</i> -Butyl)-2,4-Dinitroaniline, 385	
E18.7 Kinetics of the Reaction of 2,4-Dinitroanisole with <i>n</i> -Butylamine in Methanol, 385	
Unit 19 Diels–Alder Reaction	391
19.1 Diels–Alder Reaction, 391	
19.2 Endo versus Exo, 392	
19.3 Solvent Effects, 393	
19.4 Experimental Considerations: Following the Reaction, 395	
<i>Experiment 19A Diels–Alder Reactions in Toluene</i>	398
E19A.1 Reaction of 9-Anthraldehyde with Maleic Anhydride, 398	
E19A.2 Reaction of Phencyclone with Norbornadiene, 400	
<i>Experiment 19B Diels–Alder Reaction in Water</i>	408
E19B.1 Reaction of 9-Anthracenemethanol with <i>N</i> -Ethylmaleimide, 408	
E19B.2 Kinetics of the Reaction of 9-Anthracenemethanol with NEM, 409	
Unit 20 Aldehydes and Ketones	415
20.1 Introduction, 415	
20.2 Preparation, 416	
20.3 Reactions of Aldehydes and Ketones, 416	
20.4 IR and NMR of Aldehydes and Ketones, 423	