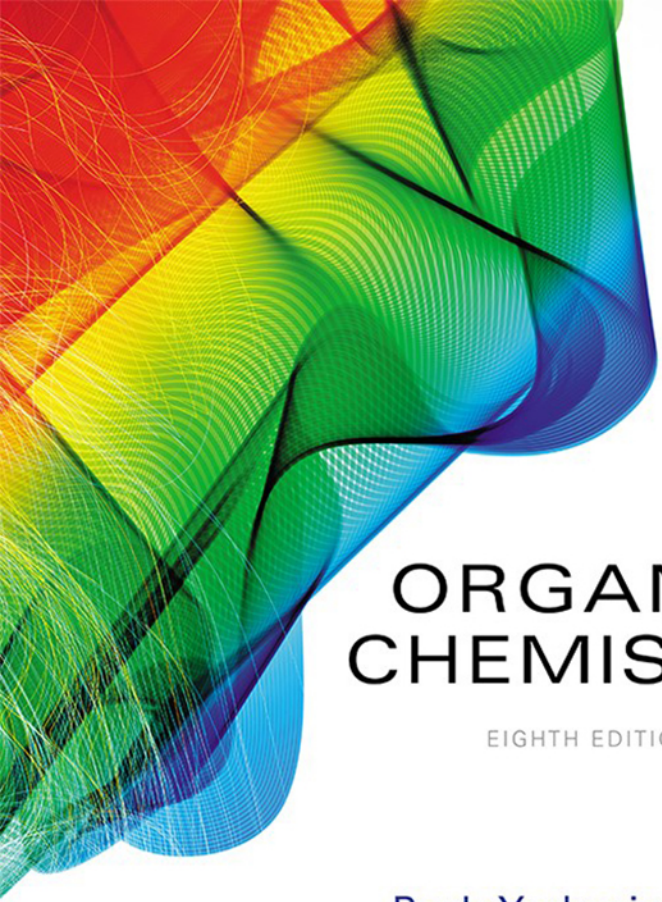

ORGANIC CHEMISTRY

EIGHTH EDITION

Paula Yurkanis Bruice

Organic Chemistry

EIGHTH EDITION

Paula Yurkanis Bruice

University Of California
Santa Barbara

PEARSON

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To Meghan, Kenton, and Alec
with love and immense respect
and to Tom, my best friend

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MasteringChemistry®

for Organic Chemistry

Mastering Chemistry tutorials guide you through the toughest topics in chemistry with self-paced tutorials that provide individualized coaching. These assignable, in-depth tutorials are designed to coach you with hints and feedback specific to your individual misconceptions. For additional practice on Molecular Models, go to MasteringChemistry where the following tutorials are available:

- Basics of Model Building
- Building and Recognizing Chiral Molecules
- Recognizing Chirality in Cyclic Molecules

Using the *E,Z* system to name alkenes was moved to Chapter 4, so now it appears immediately after using cis and trans to distinguish alkene stereoisomers.

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For additional practice on Interconverting Structural Representations, go to MasteringChemistry where the following tutorials are available:

- Interconverting Fischer Projections and Perspective Formulas
- Interconverting Perspective Formulas, Fischer Projections, and Skeletal Structures
- Interconverting Perspective Formulas, Fischer Projections, and Newman Projections

Catalytic hydrogenation and relative stabilities of alkenes were moved from Chapter 6 to Chapter 5 (thermodynamics), so they can be used to illustrate how $\Delta H°$ values can be used to determine relative stabilities.

All the reactions in Chapter 6 follow the same mechanism the first step is always addition of the electrophile to the sp^2 carbon bonded to the most hydrogens.

Chapter 8 starts by discussing the structure of benzene because it is the ideal compound to use to explain delocalized electrons. This chapter also includes a discussion of aromaticity, so a short introduction to electrophilic aromatic substitution reactions is now included. This allows students to see how aromaticity causes benzene to undergo electrophilic substitution rather than electrophilic addition—the reactions they have just finished studying.

Traditionally, electronic effects are taught so students can understand the directing effects of substituents on benzene rings. Now that most of the chemistry of benzene follows carbonyl chemistry, students need to know about electronic effects before they get to benzene chemistry (so they are better prepared for spectroscopy and carbonyl chemistry). Therefore, electronic effects are now discussed in Chapter 8 and used to teach students how substituents affect the pK_a values of phenols, benzoic acids, and anilinium ions. Electronic effects are then reviewed in the chapter on benzene.

The two chapters in the previous edition on substitution and elimination reactions of alkenes have been combined into one chapter. The recent compelling evidence showing that secondary alkyl halides do not undergo S_N1 solvolysis reactions has allowed this material to be greatly simplified, so now it fits nicely into one chapter.

The discussion of palladium-catalyzed coupling reactions has been expanded, and the cyclic catalytic mechanisms are shown.

MasteringChemistry®

for Organic Chemistry

MasteringChemistry tutorials guide you through the toughest topics in chemistry with self-paced tutorials that provide individualized coaching. These assignable, in-depth tutorials are designed to coach you with hints and feedback specific to your individual misconceptions. For additional practice on Drawing Curved Arrows in Radical Systems, go to MasteringChemistry where the following tutorials are available:

- Curved Arrows in Radical Systems: Interpreting Curved Arrows
- Curved Arrows in Radical Systems: Drawing Curved Arrows
- Curved Arrows in Radical Systems: Drawing Resonance Contributors

In addition to the more than 170 spectroscopy problems in Chapters 13 and 14, there are 60 additional spectroscopy problems in the *Study Guide and Solutions Manual*.

Chapters 13 and 14 are modular, so they can be covered at any time.

The focus of the first chapter on carbonyl chemistry is all about how a tetrahedral intermediate partitions. If students understand this, then carbonyl chemistry becomes pretty straightforward. I found that the lipid materil that had been put into this chapter in the last edition detracted from the main message of the chapter. Therefore, the lipid material was removed and put into a new chapter exclusively about lipids.

Increased emphasis on the connection between the reactions that occur in the laboratory and those that occur in cells.

Preface

The guiding principle behind this book is to present organic chemistry as an exciting and vitally important science. To counter the impression that the study of organic chemistry consists primarily of memorizing a multitude of facts, I have organized this book around shared features and unifying concepts, while emphasizing principles that can be applied again and again. I want students to apply what they have learned to new settings and to learn how to reason their way to solutions. I also want them to see that organic chemistry is a fascinating discipline that is integral to their daily lives.

Preparing Students for Future Study in a Variety of Scientific Disciplines

This book organizes the functional groups around mechanistic similarities. When students see their first reaction (other than an acid–base reaction), they are told that all organic compounds can be divided into families and that all members of a family react *in the same way*. And to make things even easier, each family can be put into one of four groups, and all the families in a group react *in similar ways*.

"Organizing What We Know About Organic Chemistry" is a feature based on these statements. It lets students see where they have been and where they are going as they proceed through each of the four groups. It also encourages them to remember the fundamental reason behind the reactions of all organic compounds: *electrophiles react with nucleophiles*. When students finish studying a particular group, they are given the opportunity to review the group and understand why the families came to be members of that particular group. The four groups are covered in the following order. (However, the book is written to be modular, so they could be covered in any order.)

- **Group I: Compounds with carbon-carbon double and triple bonds**. These compounds are nucleophiles and, therefore, react with electrophiles—undergoing electrophilic addition reactions.
- **Group II: Compounds with electron-withdrawing atoms or groups attached to sp^3 carbons**. These compounds are electrophiles and, therefore, react with nucleophiles—undergoing nucleophilic substitution and elimination reactions.
- **Group III: Carbonyl compounds**. These compounds are electrophiles and, therefore, react with nucleophiles—undergoing nucleophilic acyl substitution, nucleophilic addition, and nucleophilic addition-elimination reactions. Because of the "acidity" of the α-carbon, a carbonyl compound can become a nucleophile and, therefore, react with electrophiles.
- **Group IV: Aromatic compounds**. Some aromatic compounds are nucleophiles and, therefore, react with electrophiles—undergoing electrophilic aromatic substitution reactions. Other aromatic compounds are electrophiles and, therefore, react with nucleophiles—undergoing nucleophilic aromatic substitution reactions.

The organization discourages rote memorization and allows students to learn reactions based on their pattern of reactivity. It is only after these patterns of reactivity are understood that a deep understanding of organic chemistry can begin. As a result, students achieve the predictive capacity that is the beauty of studying science. A course that teaches students to analyze, classify, explain, and predict gives them a strong foundation to bring to their subsequent study of science, regardless of the discipline.

As students proceed through the book, they come across ~200 interest boxes that connect what they are studying to real life. Students don't have to be preparing for a career in medicine to appreciate a box on the experimental drug used to treat Ebola, and they don't have to be preparing for a career in engineering to appreciate a box on the properties that a polymer used for dental impressions must have.

The Organization Ties Together Reactivity and Synthesis

Many organic chemistry textbooks discuss the synthesis of a functional group and the reactivity of that group sequentially, but these two groups of reactions generally have little to do with one another. Instead, when I discuss a functional group's reactivity, I cover the synthesis of compounds that are formed as a result of that reactivity, often by having students design syntheses. In Chapter 6, for example, students learn about the *reactions* of alkenes, but they *do not* learn about the *synthesis* of alkenes. Instead, they learn about the synthesis of alkyl halides, alcohols, ethers, epoxides, alkanes, etc.—the compounds formed when alkenes react. The synthesis of alkenes is not covered until the reactions of alkyl halides and alcohols are discussed—compounds whose reactions lead to the synthesis of alkenes.

This strategy of tying together the reactivity of a functional group and the synthesis of compounds resulting from its reactivity prevents the student from having to memorize lists of unrelated reactions. It also results in a certain economy of presentation, allowing more material to be covered in less time.

Although memorizing different ways a particular functional group can be prepared can be counterproductive to enjoying organic chemistry, it is useful to have such a compilation of reactions when designing multistep syntheses. For this reason, lists of reactions that yield a particular functional group are compiled in Appendix III. In the course of learning how to design syntheses, students come to appreciate the importance of reactions that change the carbon skeleton of a molecule; these reactions are compiled in Appendix IV.

Helping Students Learn and Study Organic Chemistry

As each student generation evolves and becomes increasingly diverse, we are challenged as teachers to support the unique ways students acquire knowledge, study, practice, and master a subject. In order to support contemporary students who are often visual learners, with preferences for interactivity and small "bites" of information, I have revisited this edition to make it more compatible with their learning style by streamlining the narrative and using organizing bullets and subheads. This will allow them to study more efficiently with the text.

The book is written much like a tutorial. Each section ends with a set of problems that students need to work through to find out if they are ready to go on to the next section, or if they need to review the section they thought they had just mastered. This allows the book to work well in a "flipped classroom."

For those who teach organic chemistry after one semester of general chemistry, Chapter 5 and Appendix II contain material on thermodynamics and kinetics, so those topics can be taught in the organic course.

An enhanced art program with new and expanded annotations provides key information to students so that they can review important parts of the chapter with the support of the visual program. Margin notes throughout the book succinctly repeat key points and help students review important material at a glance.

Tutorials follow relevant chapters to help students master essential skills:

- Acids and Bases
- Using Molecular Models
- Interconverting Structural Representations
- Drawing Curved Arrows
- Drawing Resonance Contributors
- Drawing Curved Arrows in Radical Systems
- Synthesis and Retrosynthetic analysis

MasteringChemistry includes additional online tutorials on each of these topics that can be assigned as homework or for test preparation.

Organizational Changes

Using the *E,Z* system to distinguish alkene stereoisomers was moved to Chapter 4, so now it appears immediately after using cis and trans to distinguish alkene stereoisomers.

Catalytic hydrogenation and the relative stabilities of alkenes was moved from Chapter 6 to Chapter 5 (thermodynamics), so it can be used to illustrate how $\Delta H°$ values can be used to determine relative stabilities. Moving this has another advantage—because catalytic hydrogenation is the only reaction of alkenes that does not have a well-defined mechanism, all the remaining reactions

in Chapter 6 now have well-defined mechanisms, all following the general rule that applies to all electrophilic addition reactions: the first step is always the addition of the electrophile to the sp^2 carbon bonded to the most hydrogens.

Chapter 8 starts by discussing the structure of benzene because it is the ideal compound to use to explain delocalized electrons. This chapter also includes a discussion on aromaticity, so a short introduction to electrophilic aromatic substitution reactions is now included. This allows students to see how aromaticity causes benzene to undergo electrophilic substitution rather than electrophilic addition—the reactions they just finished studying.

Traditionally, electronic effects are taught so students can understand the activating and directing effects of substituents on benzene rings. Now that most of the chemistry of benzene follows carbonyl chemistry, students need to know about electronic effects before they get to benzene chemistry (so they are better prepared for spectroscopy and carbonyl chemistry). Therefore, in this edition electronic effects are discussed in Chapter 8 and used to teach students how substituents affect the pK_a values of phenols, benzoic acids, and anilinium ions. Electronic effects are then reviewed in the chapter on benzene.

The two chapters in the previous edition that covered the substitution and elimination reactions of alkyl halides have been combined into one chapter (Chapter 9). The recent compelling evidence showing that alkyl halides do not undergo S_N1 solvolysis reactions has allowed this material to be greatly simplified, so now it fits nicely into one chapter.

I have found that teaching carbonyl chemistry before the chemistry of aromatic compounds (a change made in the last edition) has worked well for my students. Carbonyl compounds are probably the most important organic compounds, and moving them forward gives them the prominence they should have. In addition, the current location of the chemistry of benzene allows it and the chemistry of aromatic heterocyclic compounds to be taught sequentially.

The focus of the first chapter on carbonyl chemistry should be all about how a tetrahedral intermediate partitions. If students understand this, then carbonyl chemistry becomes relatively easy. I found that the lipid material that had been put into this chapter detracted from the main message of the chapter. Therefore, the lipid material was removed and put into a new chapter: The Organic Chemistry of Lipids. The discussion of terpenes from the metabolism chapter has also been moved into this chapter, and some some new material has been included.

Modularity/Spectroscopy

The book is designed to be modular, so the four groups (Group I—Chapters 6, 7, 8; Group II—Chapters 9 and 10; Group III—Chapters 15, 16, 17; Group IV—Chapters 18 and 19) can be covered in any order.

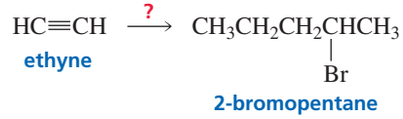
Sixty spectroscopy problems and their answers—in addition to ~170 spectroscopy problems in the text—can be found in the *Study Guide and Solutions Manual*. The spectroscopy chapters (Chapters 13 and 14) are written so that they can be covered at any time during the course. For those who prefer to teach spectroscopy before all the functional groups have been introduced—or in a separate laboratory course—there is a table of functional groups at the beginning of Chapter 13.

An Early and Consistent Emphasis on Organic Synthesis

Students are introduced to synthetic chemistry and retrosynthetic analysis early in the book (Chapters 6 and 7, respectively), so they can start designing multistep syntheses early in the course. Seven special sections on synthesis design, each with a different focus, are introduced at appropriate intervals. There is also a tutorial on synthesis and retrosynthetic analysis that includes some examples of complicated multistep syntheses from the literature.

Example 2

Starting with ethyne, how could you make 2-bromopentane?



2-Bromopentane can be prepared from 1-pentene, which can be prepared from 1-pentyne. 1-Pentyne can be prepared from ethyne and an alkyl halide with three carbons.

Problems, Solved Problems, and Problem-Solving Strategies

The book contains more than 2,000 problems, many with multiple parts. This edition has many new problems, both in-chapter and end-of-chapter. They include new solved problems, new problem-solving strategies, and new problems incorporating information from more than one chapter. I keep a list of questions my students have when they come to office hours. Many of the new problems were created as a result of these questions.

The answers (and explanations, when needed) to all the problems are in the accompanying *Study Guide/Solutions Manual*, which I authored to ensure consistency in language with the text. The problems within each chapter are primarily drill problems. They appear at the end of each section, so they allow students to test themselves on material just covered before moving on to the next section. Short answers provided at the end of the book for problems marked with a diamond give students immediate feedback concerning their mastery of a skill or concept.

Selected problems are accompanied by worked-out solutions to provide insight into problem-solving techniques, and the many Problem-Solving Strategies teach students how to approach various kinds of problems. These skill-teaching problems are indicated by LEARN THE STRATEGY in the margin. These strategies are followed by one or more problems that give students the opportunity to use the strategy just learned. These problems, or the first of a group of such problems, are indicated in the margin by USE THE STRATEGY.

The *Study Guide/Solutions Manual* has a practice test at the end of each chapter and contains Special Topics Sections on molecular orbital theory and how to solve problems on pH, pK_a, and buffer solutions.

Powerpoint

All the art in the text is available on PowerPoint slides. I created the PowerPoint lectures so they would be consistent with the language and philosophy of the text.

Students Interested in The Biological Sciences and MCAT[2015]

I have long believed that students who take organic chemistry also should be exposed to bioorganic chemistry—the organic chemistry that occurs in biological systems. Students leave their organic chemistry course with a solid appreciation of organic mechanism and synthesis. But when they take biochemistry, they will never hear about Claisen condensations, S_N2 reactions, nucleophilic acyl substitution reactions, etc., although these are extremely important reactions in cells. Why are students required to take organic chemistry if they are not going to be taught how the organic chemistry they learn repeats itself in the biological world?

Now that the MCAT is focusing almost exclusively on the organic chemistry of living systems, it is even more important that we provide our students with the "bioorganic bridge"—the material that provides the bridge between organic chemistry and biochemistry. Students should see that the organic reactions that chemists carry out in the laboratory are in many ways the same as those performed by nature inside a cell.

The seven chapters (Chapters 20–26) that focus primarily on the organic chemistry of living systems emphasize the connection between the organic reactions that occur in the laboratory and those that occur in cells.

> *Each organic reaction that occurs in a cell is explicitly compared to the organic reaction with which the student is already familiar.*

For example, the first step in glycolysis is an S_N2 reaction, the second step is identical to the enediol rearrangement that students learn when they study carbohydrate chemistry, the third step is another S_N2 reaction, the fourth step is a reverse aldol addition, and so on. The first step in the citric acid cycle is an aldol addition followed by a nucleophilic acyl substitution reaction, the second step is an E2 dehydration followed by the conjugate addition of water, the third step is oxidation of a secondary alcohol followed by decarboxylation of a 3-oxocarboxylate ion, and so on.

We teach students about halide and sulfonate leaving groups. Adding phosphate leaving groups takes little additional time but introduces the students to valuable information if they are going on to study biochemistry.

Students who study organic chemistry learn about tautomerization and imine hydrolysis, and students who study biochemistry learn that DNA has thymine bases in place of the uracil bases in RNA. But how many of these students are ever told that the reason for the difference in the bases in DNA and RNA is tautomerization and imine hydrolysis?

Colleagues have asked how they can find time to fit the "bioorganic bridge" into their organic chemistry courses. I found that tying together reactivity and synthesis (see p. xxiii) frees up a lot of time. (This is the organization I adopted many years ago when I was trying to figure out how to incorporate the bioorganic bridge into my course.) And if you find that this still does not give you enough time, I have organized the book in a way that allows some "traditional" chapters to be omitted (Chapters 12, 18, 19, and 28), so students can be prepared for biochemistry and/or the MCAT without sacrificing the rigor of the organic course.

The Bioorganic Bridge

Bioorganic chemistry is found throughout the text to show students that organic chemistry and biochemistry are not separate entities but rather are closely related on a continuum of knowledge. Once students learn how, for example, electron delocalization, leaving-group propensity, electrophilicity, and nucleophilicity affect the reactions of simple organic compounds, they can appreciate how these same factors influence the reactions of organic compounds in cells.

In Chapters 1–19, the bioorganic material is limited mostly to "interest boxes" and to the last sections of the chapters. Thus, the material is available to the curious student without requiring the instructor to introduce bioorganic topics into the course. For example, after hydrogen bonding is introduced in Chapter 3, hydrogen boding in proteins in DNA is discussed; after catalysis is introduced in Chapter 5, catalysis by enzymes is discussed; after the stereochemistry of organic reactions is presented in Chapter 6, the stereochemistry of enzyme-catalyzed reactions is discussed; after sulfonium ions are discussed in Chapter 10, a biological methylation reaction using a sulfonium ion is examined and the reason for the use of different methylating agents by chemists and cells is explained; after the methods chemists use to activate carboxylic acids are presented (by giving them halide or anhydride leaving groups) in Chapter 15, the methods cells use to activate these same acids are explained (by giving them phosphoanhydride, pyrophosphate, or thiol leaving groups); and after condensation reactions are discussed in Chapter 17, the mechanisms of some biological condensation reactions are shown.

In addition, seven chapters in the last part of the book (Chapters 20–26) focus on the organic chemistry of living systems. These chapters have the unique distinction of containing more chemistry than is typically found in the corresponding parts of a biochemistry text. Chapter 22 (Catalysis in Organic Reactions and in Enzymatic Reactions), for example, explains the various modes of catalysis employed in organic reactions and then shows that they are identical to the modes of catalysis found in reactions catalyzed by enzymes. All of this is presented in a way that allows students to understand the lightning-fast rates of enzymatic reactions. Chapter 23 (The Organic Chemistry of the Coenzymes, Compounds Derived from Vitamins) emphasizes the role of vitamin B_1 in electron delocalization, vitamin K as a strong base, vitamin B_{12} as a radical initiator, biotin as a compound that transfers a carboxyl group by means of a nucleophilic acyl substitution reaction, and describes how the many different reactions of vitamin B_6 have common mechanisms—with the first step always being imine formation. Chapter 24 (The Organic Chemistry of Metabolic Pathways) explains the chemical function of ATP and shows students that the reactions encountered in metabolism are just additional examples of reactions that they already have mastered. In Chapter 26 (The Chemistry of the Nucleic Acids), students learn that 2′-OH group on the ribose molecules in RNA catalyzes its hydrolysis and that is why DNA, which has to stay intact for the life of the cell, does not have 2′-OH groups. Students also see that the synthesis of proteins in cells is just another example of a nucleophilic acyl substitution reaction. Thus, these chapters do not replicate what will be covered in a biochemistry course; they provide a bridge between the two disciplines, allowing students to see how the organic chemistry that they have learned is repeated in the biological world.

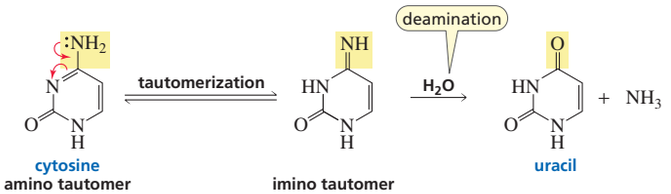
ENGAGING MIXED SCIENCE MAJORS IN ORGANIC CHEMISTRY

Students better understand the relevance of what they're studying by seeing the connections between the reactions of organic compounds that occur in the laboratory and those that occur in a cell. Changes throughout this edition provide students with this much-needed "bioorganic bridge," while maintaining the rigor of the traditional organic course.

For example, we teach students about halide and sulfonate leaving groups. Adding phosphate leaving groups takes little additional time, but it introduces students to valuable information, particularly if they are taking organic chemistry because of an interest in the biological sciences. Students who are studying organic chemistry learn about tautomerization and imine hydrolysis, and students studying biochemistry learn that DNA has thymine bases in place of the uracil bases in RNA. But how many of these students are ever told that the reason for the difference in the bases in DNA and RNA is tautomerization and imine hydrolysis?

The $NADP^+$ formed in this reaction has to be reduced back to NADPH by NADH. Every NADH formed in a cell can result in the formation of 2.5 ATPs (Section 24.10). Therefore, reducing dihydrofolate comes at the expense of ATP. This means that the synthesis of thymine is energetically expensive, so there must be a good reason for DNA to contain thymine instead of uracil.

The presence of thymine instead of uracil in DNA prevents potentially lethal mutations. Cytosine can tautomerize to form an imine (Section 17.2), which can be hydrolyzed to uracil (Section 16.8). The overall reaction is called a **deamination** because it removes an amino group.



More Applications Than Any Other Organic Text

NEW! and Updated Application boxes connect the discussion to medical, environmental, biological, pharmaceutical, nutritional, chemical, industrial, historical, and general applications and allow students to relate the material to real life and to potential future careers.

Using Genetic Engineering to Treat the Ebola Virus

Plants have long been a source of drugs—morphine, ephedrine, and codeine are just a few examples (Section 10.9). Now scientists are attempting to obtain drugs from plants by biopharming. Biopharming uses genetic engineering techniques to produce drugs in crops such as corn, rice, tomatoes, and tobacco. To date, the only biopharmed drug approved by the Food and Drug Administration (FDA) is one that is manufactured in carrots and used to treat Gaucher's disease.

An experimental drug that was used to treat a handful of patients with Ebola, the virus that was spreading throughout West Africa, was obtained from genetically engineered tobacco plants. The tobacco plants were infected with three genetically engineered plant viruses that are harmless to humans and animals but have structures similar to that of the Ebola virus. As a result of being infected, the plants produced antibodies to the viruses. The antibodies were isolated from the plants, purified, and then used to treat the patients with Ebola.

The experimental drug had been tested in 18 monkeys who had been exposed to a lethal dose of Ebola. All 18 monkeys survived, whereas the three monkeys in the control group died. Typically, drugs go through rigorous testing on healthy humans prior to being administered to infected patients (see page 290). In the Ebola case, the FDA made an exception because it feared that the drug might be these patients' only hope. Five of the seven people given the drug survived. Currently, it takes about 50 kilograms of tobacco leaves and about 4 to 6 months to produce enough drug to treat one patient.

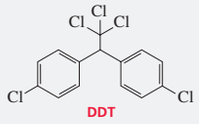
tobacco plants

The Birth of the Environmental Movement

Alkyl halides have been used as insecticides since 1939, when it was discovered that DDT (first synthesized in 1874) has a high toxicity to insects and a relatively low toxicity to mammals. DDT was used widely in World War II to control typhus and malaria in both the military and civilian populations. It saved millions of lives, but no one realized at that time that, because it is a very stable compound, it is resistant to biodegradation. In addition, DDT and DDE, a compound formed as a result of elimination of HCl from DDT, are not water soluble. Therefore, they accumulate in the fatty tissues of birds and fish and can be passed up the food chain. Most older adults have a low concentration of DDT or DDE in their bodies.

In 1962, Rachel Carson, a marine biologist, published *Silent Spring,* where she pointed out the environmental impacts of the widespread use of DDT. The book was widely read, so it brought the problem of environmental pollution to the attention of the general public for the first time. Consequently, its publication was an important event in the birth of the environmental movement. Because of the concern it raised, DDT was banned in the United States in 1972. In 2004, the Stockholm Convention banned the worldwide use of DDT except for the control of malaria in countries where the disease is a major health problem.

In Section 12.12, we will look at the environmental effects caused by synthetic alkyl halides known as chlorofluorohydrocarbons (CFCs).

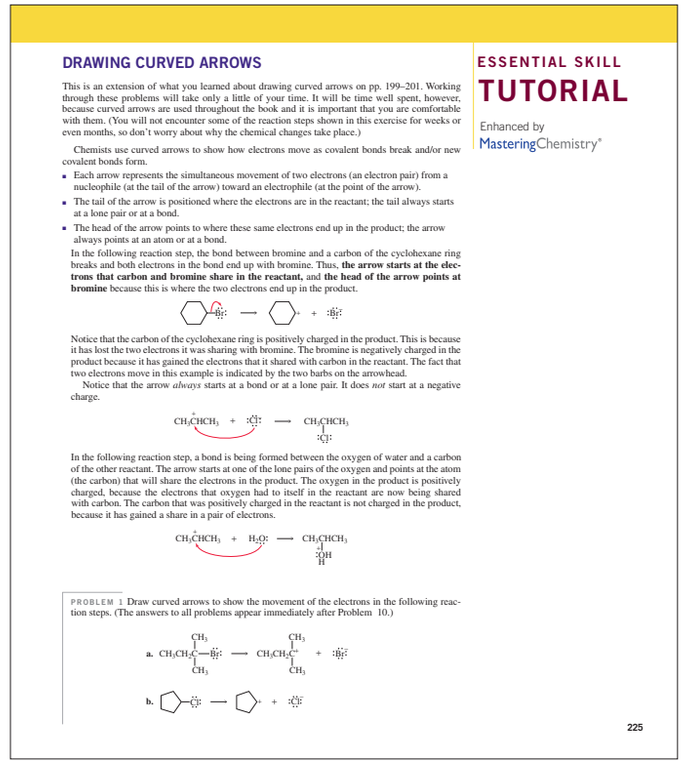


DDT

GUIDED APPROACH TO PROBLEM SOLVING

Essential Skill Tutorials

These tutorials guide students through some of the topics in organic chemistry that they typically find to be the most challenging. They provide concise explanations, related problem-solving opportunities, and answers for self-check. The print tutorials are paired with MasteringChemistry online tutorials. These are additional problem sets that can be assigned as homework or as test preparation.



DRAWING CURVED ARROWS

ESSENTIAL SKILL
TUTORIAL
Enhanced by MasteringChemistry®

This is an extension of what you learned about drawing curved arrows on pp. 199–201. Working through these problems will take only a little of your time. It will be time well spent, however, because curved arrows are used throughout the book and it is important that you are comfortable with them. (You will not encounter some of the reaction steps shown in this exercise for weeks or even months, so don't worry about why the chemical changes take place.)

Chemists use curved arrows to show how electrons move as covalent bonds break and/or new covalent bonds form.

- Each arrow represents the simultaneous movement of two electrons (an electron pair) from a nucleophile (at the tail of the arrow) toward an electrophile (at the point of the arrow).
- The tail of the arrow is positioned where the electrons are in the reactant; the tail always starts at a lone pair or at a bond.
- The head of the arrow points to where these same electrons end up in the product; the arrow always points at an atom or at a bond.

In the following reaction step, the bond between bromine and a carbon of the cyclohexane ring breaks and both electrons in the bond end up with bromine. Thus, **the arrow starts at the electrons that carbon and bromine share in the reactant,** and **the head of the arrow points at bromine** because this is where the two electrons end up in the product.

Notice that the carbon of the cyclohexane ring is positively charged in the product. This is because it has lost the two electrons it was sharing with bromine. The bromine is negatively charged in the product because it has gained the electrons that it shared with carbon in the reactant. The fact that two electrons move in this example is indicated by the two barbs on the arrowhead.

Notice that the arrow *always* starts at a bond or at a lone pair. It does *not* start at a negative charge.

In the following reaction step, a bond is being formed between the oxygen of water and a carbon of the other reactant. The arrow starts at one of the lone pairs of the oxygen and points at the atom (the carbon) that will share the electrons in the product. The oxygen in the product is positively charged, because the electrons that oxygen had to itself in the reactant are now being shared with carbon. The carbon that was positively charged in the reactant is not charged in the product, because it has gained a share in a pair of electrons.

PROBLEM 1 Draw curved arrows to show the movement of the electrons in the following reaction steps. (The answers to all problems appear immediately after Problem 10.)

a.

b.

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Organizing What We Know About the Reactivity of Organic Compounds

This organization emphasizes the unifying principles of reactivity and offers an economy of presentation while discouraging memorization. Students learn that

- organic compounds can be classified into *families* and that all members of a family react in the same way.
- the families can be put into one of four *groups* and that all the family members in a group react in similar ways.

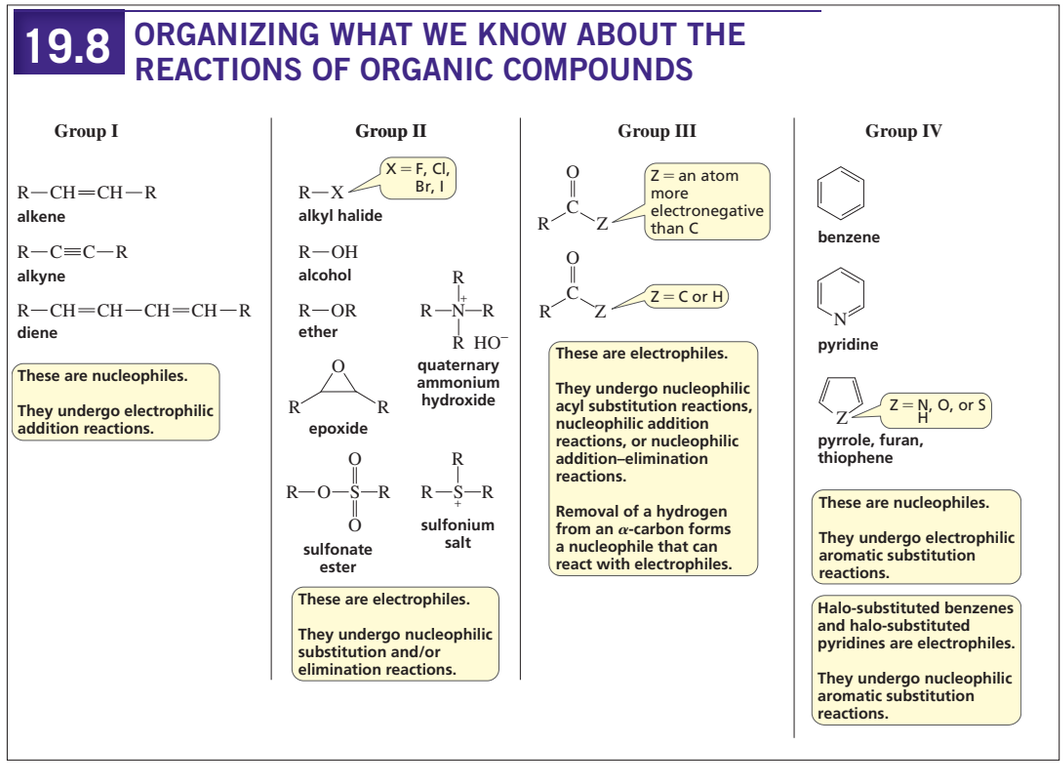
The Organizing What We Know table builds as students work sequentially through the four groups.

Group I: electrophilic addition reactions

Group II: nucleophilic substitution reactions and elimination reactions

Group III: nucleophilic acyl substitution reactions, nucleophilic addition reactions, and nucleophilic addition–elimination reactions

Group IV: electrophilic (and nucleophilic) aromatic substitution reactions



19.8 ORGANIZING WHAT WE KNOW ABOUT THE REACTIONS OF ORGANIC COMPOUNDS

Group I

R—CH=CH—R
alkene

R—C≡C—R
alkyne

R—CH=CH—CH=CH—R
diene

These are nucleophiles.
They undergo electrophilic addition reactions.

Group II

R—X (X = F, Cl, Br, I)
alkyl halide

R—OH
alcohol

R—OR
ether

quaternary ammonium hydroxide

epoxide

sulfonate ester

sulfonium salt

These are electrophiles.
They undergo nucleophilic substitution and/or elimination reactions.

Group III

Z = an atom more electronegative than C

Z = C or H

These are electrophiles.
They undergo nucleophilic acyl substitution reactions, nucleophilic addition reactions, or nucleophilic addition–elimination reactions.
Removal of a hydrogen from an α-carbon forms a nucleophile that can react with electrophiles.

Group IV

benzene

pyridine

Z = N, O, or S
H

pyrrole, furan, thiophene

These are nucleophiles.
They undergo electrophilic aromatic substitution reactions.

Halo-substituted benzenes and halo-substituted pyridines are electrophiles.
They undergo nucleophilic aromatic substitution reactions.

Emphasis on the Strategies Needed to Solve Problems and Master Content

Passages explaining important problem-solving strategies are clearly labeled with a LEARN THE STRATEGY label. Follow-up problems that require students to apply the just-learned strategy are labeled with a USE THE STRATEGY label. These labels, which are implemented throughout the text, allow students to easily find important content and practice its use.

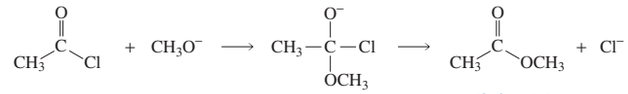
LEARN THE STRATEGY

PROBLEM-SOLVING STRATEGY

Using Basicity to Predict the Outcome of a Nucleophilic Acyl Substitution Reaction

What is the product of the reaction of acetyl chloride with CH_3O^-? The pK_a of HCl is –7; the pK_a of CH_3OH is 15.5.

To identify the product of the reaction, we need to compare the basicities of the two groups in the tetrahedral intermediate so we can determine which one will be eliminated. Because HCl is a stronger acid than CH_3OH, Cl^- is a weaker base than CH_3O^-. Therefore, Cl^- is eliminated from the tetrahedral intermediate and methyl acetate is the product of the reaction.



USE THE STRATEGY

PROBLEM 7 ♦

a. What is the product of the reaction of acetyl chloride with HO^-? The pK_a of HCl is −7; the pK_a of H_2O is 15.7.
b. What is the product of the reaction of acetamide with HO^-? The pK_a of NH_3 is 36; the pK_a of H_2O is 15.7.

PROBLEM 8 ♦

What is the product of an acyl substitution reaction—a new carboxylic acid derivative, a mixture of two carboxylic acid derivatives, or no reaction—if the new group in the tetrahedral intermediate is the following?

a. a stronger base than the substituent that is attached to the acyl group
b. a weaker base than the substituent that is attached to the acyl group
c. similar in basicity to the substituent that is attached to the acyl group

Designing a Synthesis

This recurring feature helps students learn to design multi-step syntheses and facilitates the development of complex problem-solving skills. Many problems include the synthesis of well-known compounds such as Novocain®, Valium®, and Ketoprofen®.

DESIGNING A SYNTHESIS V

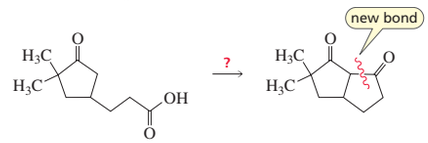
17.20 MAKING NEW CARBON–CARBON BONDS

When planning the synthesis of a compound that requires the formation of a new carbon–carbon bond:

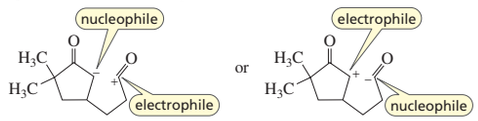
- locate the new bond that needs to be made and perform a disconnection—that is, break the bond to produce two fragments.
- determine which of the atoms that will form the new bond should be the electrophile and which should be the nucleophile.
- choose a compound with the desired electrophilic and nucleophilic groups.

Example 1

The new bond that needs to be made in the synthesis of the following β-diketone is the one that makes the second five-membered ring:



It is easy to choose between the two possibilities for the electrophile and nucleophile because we know that a carbonyl carbon is an electrophile.



If we know what the starting material is, we can use it as a clue to arrive at the desired compound. For example, an ester carbonyl group would be a good electrophile for this synthesis because it has a group that would be eliminated. Moreover, the α-hydrogens of the ketone are more acidic than the α-hydrogens of the ester, so the desired nucleophile would be easy to obtain. Thus, converting the starting material to an ester (Section 15.18), followed by an intramolecular condensation, forms the target molecule.