

# ORGANIC CHEMISTRY

*WITH BIOLOGICAL TOPICS*

FIFTH EDITION



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Hill  
Education

JANICE GORZYNSKI SMITH  
HEIDI R. VOLLMER-SNARR

# Periodic Table of the Elements

Group number → 1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
Period number → 1	2	3	4	5	6	7	8	8	8	8	8	9	10	11	12	13	14
1 <b>H</b> Hydrogen 1.0079	4 <b>Be</b> Beryllium 9.0122	21 <b>Sc</b> Scandium 44.9559	22 <b>Ti</b> Titanium 47.88	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.9380	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.9332	28 <b>Ni</b> Nickel 58.693	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.41	5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.011	7 <b>N</b> Nitrogen 14.0067	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984	18 <b>Ar</b> Argon 39.948
2 <b>Li</b> Lithium 6.941	12 <b>Mg</b> Magnesium 24.3050	20 <b>Ca</b> Calcium 40.078	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.9064	42 <b>Mo</b> Molybdenum 95.94	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	13 <b>Al</b> Aluminum 26.9815	14 <b>Si</b> Silicon 28.0855	15 <b>P</b> Phosphorus 30.9738	16 <b>S</b> Sulfur 32.066	17 <b>Cl</b> Chlorine 35.4527	18 <b>Ar</b> Argon 39.948
3 <b>Na</b> Sodium 22.9898	19 <b>K</b> Potassium 39.0983	39 <b>Y</b> Yttrium 88.9059	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.9064	42 <b>Mo</b> Molybdenum 95.94	43 <b>Tc</b> Technetium (98)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.64	33 <b>As</b> Arsenic 74.9216	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.80
4 <b>Ca</b> Calcium 40.078	20 <b>Ca</b> Calcium 40.078	38 <b>Sr</b> Strontium 87.62	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.9479	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.2	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.9665	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)
5 <b>Rb</b> Rubidium 85.4678	37 <b>Rb</b> Rubidium 85.4678	57 <b>La</b> Lanthanum 138.9055	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.9479	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.2	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.9665	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.9804	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (210)	86 <b>Rn</b> Radon (222)
6 <b>Cs</b> Cesium 132.9054	55 <b>Cs</b> Cesium 132.9054	89 <b>Ac</b> Actinium (227)	104 <b>Rf</b> Rutherfordium (267)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Fl</b> Flerovium (284)	114 <b>Po</b> Livermorium (293)	115 <b>Lv</b> Tennessine (294)	116 <b>Lv</b> Tennessine (294)	117 <b>Uu</b> Oganesson (294)	118 <b>Xe</b> Xenon 131.29
7 <b>Fr</b> Francium (223)	87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	104 <b>Rf</b> Rutherfordium (267)	105 <b>Db</b> Dubnium (268)	106 <b>Sg</b> Seaborgium (271)	107 <b>Bh</b> Bohrium (272)	108 <b>Hs</b> Hassium (270)	109 <b>Mt</b> Meitnerium (276)	110 <b>Ds</b> Darmstadtium (281)	111 <b>Rg</b> Roentgenium (280)	112 <b>Cn</b> Copernicium (285)	113 <b>Fl</b> Flerovium (284)	114 <b>Po</b> Livermorium (293)	115 <b>Lv</b> Tennessine (294)	116 <b>Lv</b> Tennessine (294)	117 <b>Uu</b> Oganesson (294)	118 <b>Xe</b> Xenon 131.29
			Lanthanides						Actinides								
			58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.9076	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.9253	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.9303	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.9342	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967	88 <b>Ra</b> Radium (226)
			90 <b>Th</b> Thorium 232.0381	91 <b>Pa</b> Protactinium 231.0359	92 <b>U</b> Uranium 238.0289	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (260)	89 <b>Ac</b> Actinium (227)

Atomic number → 67

Name → Ho

Symbol → Ho

Atomic weight → 164.9303

An element

# Organic Chemistry with Biological Topics

Fifth Edition

Janice Gorzynski Smith

University of Hawai'i at Mānoa

Heidi R. Vollmer–Snarr

Stanford University



## ORGANIC CHEMISTRY WITH BIOLOGICAL TOPICS, FIFTH EDITION

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## About the Authors



**Janice Gorzynski Smith** was born in Schenectady, New York. She received an A.B. degree *summa cum laude* in chemistry from Cornell University and a Ph.D. in organic chemistry from Harvard University under the direction of Nobel Laureate E. J. Corey. After a postdoctoral fellowship, Jan joined the faculty of Mount Holyoke College, where she was employed for 21 years, teaching organic chemistry and conducting a research program in organic synthesis. After spending two sabbaticals in Hawai'i in the 1990s, Jan and her family moved there permanently in 2000, and she became a faculty member at the University of Hawai'i at Mānoa. She has four children and four grandchildren. When not teaching, writing, or enjoying her family, Jan bikes, hikes, snorkels, and scuba dives, and time permitting, enjoys travel and quilting.



**Heidi R. Vollmer-Snarr** was born in Pittsburgh, Pennsylvania. She received a B.S. degree in chemistry and a B.A. degree in German from the University of Utah and a Ph.D. in organic chemistry from Oxford University under the direction of Sir Jack Baldwin. As an NIH Postdoctoral Fellow, she worked for Koji Nakanishi at Columbia University and was an Assistant Professor at Brigham Young University, where her research involved the synthesis and photochemistry of ocular retinoid age pigments. Heidi now focuses on curriculum development at Stanford University and serves on the NIH Small Business Sensory Technologies study section and ACS Committee on Chemistry and Public Affairs. She also loves to spend time skiing, biking, and hiking with her husband, Trent, and three children, Zach, Grady, and Elli.

*F*or Megan Sarah Smith and Charles J. Vollmer

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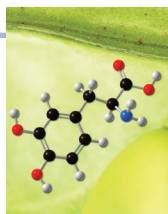
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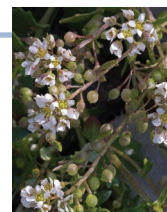
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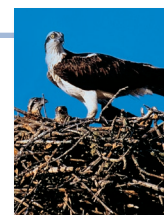
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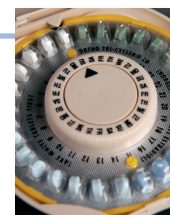
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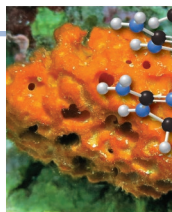
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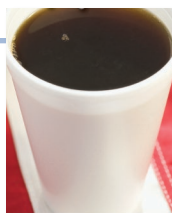
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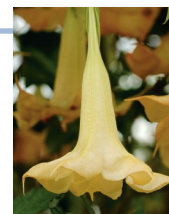
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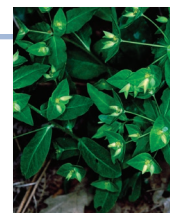
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# Preface

Since the publication of *Organic Chemistry* in 2005, chemistry has witnessed a rapid growth in its understanding of the biological world. The molecular basis of many complex biological processes is now known with certainty, and can be explained by applying the basic principles of organic chemistry. Because of the close relationship between chemistry and many biological phenomena, *Organic Chemistry with Biological Topics* presents an approach to traditional organic chemistry that incorporates the discussion of biological applications that are understood using the fundamentals of organic chemistry.

## The Basic Features

*Organic Chemistry with Biological Topics* continues the successful student-oriented approach used in *Organic Chemistry* by Janice Gorzynski Smith. This text uses less prose and more diagrams and bulleted summaries for today's students, who rely more heavily on visual imagery to learn than ever before. Each topic is broken down into small chunks of information that are more manageable and easily learned. Sample Problems illustrate stepwise problem solving, and relevant examples from everyday life are used to illustrate topics. New concepts are introduced one at a time so that the basic themes are kept in focus.

The organization of *Organic Chemistry with Biological Topics* provides the student with a logical and accessible approach to an intense and fascinating subject. The text begins with a healthy dose of review material in Chapters 1 and 2 to ensure that students have a firm grasp of the fundamentals. Stereochemistry, the three-dimensional structure of molecules, is introduced early (Chapter 5) and reinforced often. Certain reaction types with unique characteristics and terminology are grouped together. These include acid–base reactions (Chapter 2), oxidation and reduction (Chapters 12 and 20), radical reactions (Chapter 15), and reactions of organometallic reagents (Chapter 20). Each chapter ends with Key Concepts, end-of-chapter summaries that succinctly organize the main concepts and reactions.

## New to *Organic Chemistry with Biological Topics*

While there is no shortage of biological applications that can be added to an organic chemistry text, we have chosen to concentrate on the following areas.

- **Chapter 3** on functional groups now includes an expanded section on four types of biomolecules—amino acids and proteins, monosaccharides and carbohydrates, nucleotides and nucleic acids, and lipids. This material augments the discussions of vitamins and the cell membrane, topics already part of *Organic Chemistry* in past editions. Phosphorus-containing compounds such as ATP (adenosine triphosphate), the key intermediate used in energy transfer in cells, are also introduced in this chapter.
- **Chapter 6** now uses biological examples to illustrate the basic types of organic reactions, and the energetics of coupled reactions in metabolism is presented. The discussion of enzymes as biological catalysts is expanded, and a specific example of an enzyme's active site is shown.
- **Chapter 17** now applies the discussion of aromatic heterocycles to the bases in DNA, the high molecular weight molecule that holds the encrypted genetic instructions for our development and cellular processes. In addition, new material has been added on the synthesis of female sex hormones with the aromatase enzyme, which has resulted in the development of drugs used to treat estrogen-dependent breast cancers.

- **Chapter 19** contains a section on the Henderson–Hasselbalch equation, a mathematical expression that allows us to tell whether a compound exists as an uncharged compound or ion at the cellular pH of 7.4. A section on phosphoric acid esters has been added, and the ionization of amino acids is now explained using the Henderson–Hasselbalch equation.
- **Chapter 22** contains additional material on two common carboxylic acid derivatives—acyl phosphates and thioesters. The role of these functional groups in the biosynthesis of amino acids and the metabolism of fatty acids is discussed.
- **Chapter 24** contains a new section on biological carbonyl condensation reactions. Topics include the biological aldol reaction in the citric acid cycle, the retro-aldol reaction in the metabolism of glucose, and the biological Claisen reaction in the biosynthesis of fatty acids.

In addition, the later chapters of the text are now reorganized to emphasize the connection of biomolecules to prior sections. The chapter on Amino Acids and Proteins (Chapter 26) now directly follows the chapter on Amines (Chapter 25), followed by the remaining chapters on biomolecules, Carbohydrates (Chapter 27) and Lipids (Chapter 28).





# Tools to Make Learning Organic Chemistry Easier

## Illustrations

*Organic Chemistry with Biological Topics* is supported by a well-developed illustration program. Besides traditional skeletal (line) structures and condensed formulas, there are numerous ball-and-stick molecular models and electrostatic potential maps to help students grasp the three-dimensional structure of molecules (including stereochemistry) and to better understand the distribution of electronic charge.

## Micro-to-Macro Illustrations

Unique to *Organic Chemistry with Biological Topics* are micro-to-macro illustrations, where line art and photos combine with chemical structures to reveal the underlying molecular structures giving rise to macroscopic properties of common phenomena. Examples include starch and cellulose (Chapter 5), adrenaline (Chapter 7), partial hydrogenation of vegetable oil (Chapter 12), and dopamine (Chapter 25).

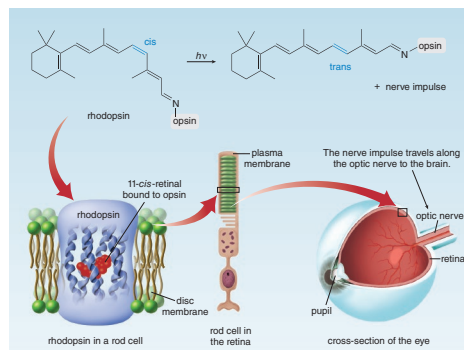
## Spectra

Over 100 spectra created specifically for *Organic Chemistry with Biological Topics* are presented throughout the text. The spectra are color-coded by type and generously labeled. Mass spectra are green; infrared spectra are red; and proton and carbon nuclear magnetic resonance spectra are blue.

## Mechanisms

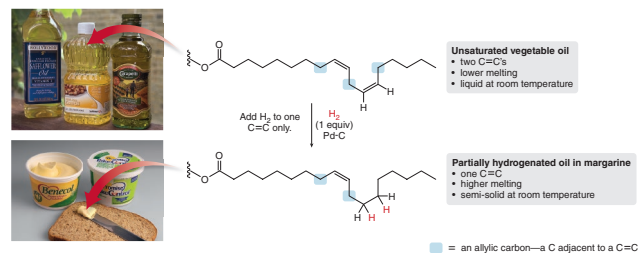
Curved arrow notation is used extensively to help students follow the movement of electrons in reactions.

Figure 21.9  
The key reaction in the chemistry of vision



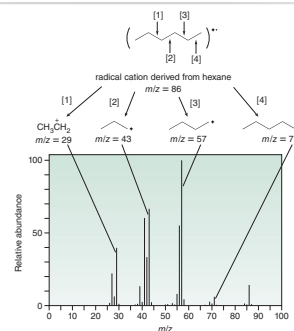
Rhodopsin is a light-sensitive compound located in the membrane of the rod cells in the retina of the eye. Rhodopsin contains the protein opsin bonded to 11-cis-retinal via an imine linkage. When light strikes this molecule, the crowded 11-cis double bond isomerizes to the 11-trans isomer, and a nerve impulse is transmitted to the brain by the optic nerve.

Figure 12.4 Partial hydrogenation of the double bonds in a vegetable oil



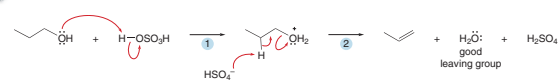
Decreasing the number of degrees of unsaturation increases the melting point. Only one long chain of the triacylglycerol is drawn. When an oil is partially hydrogenated, some double bonds react with  $H_2$ , whereas some double bonds remain in the product. Partial hydrogenation decreases the number of allylic sites (shown in blue), making a triacylglycerol less susceptible to oxidation, thereby increasing its shelf life.

Figure 13.5  
Identifying fragments in the mass spectrum of hexane



Cleavage of C—C bonds (labeled [1]–[4]) in hexane forms lower molecular weight fragments that correspond to lines in the mass spectrum. Although the mass spectrum is complex, possible structures can be assigned to some of the fragments, as shown.

Mechanism 9.2 Dehydration of a 1° ROH—An E2 Mechanism




1 Protonation of the oxygen atom converts the poor leaving group ( $^-OH$ ) into a good leaving group ( $H_2O$ ).  
2 Two bonds are broken and two bonds are formed. The base ( $HSO_4^-$  or  $H_2O$ ) removes a proton from the  $\beta$  carbon; the electron pair in the  $\beta$  C—H bond forms the new  $\pi$  bond and the leaving group ( $H_2O$ ) departs.

## Problem Solving

### Sample Problems

Sample Problems show students how to solve organic chemistry problems in a logical, stepwise manner. More than 800 follow-up problems are located throughout the chapters to test whether students understand concepts covered in the Sample Problems.

Sample Problem 4.1 Give the IUPAC name for the following compound.



**Solution**  
To help identify which carbons belong to the longest chain and which are substituents, box in or highlight the atoms of the long chain. Every other carbon atom then becomes a substituent that needs its own name as an alkyl group.

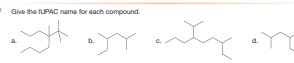
**Step 1: Name the parent.**  
9 C's in the longest chain  
**pentane**

**Step 2: Number the chain.**  
first substituent at C3

**Step 3: Name and number the substituents.**  
tert-butyl at C4  
methyl at C3

**Step 4: Combine the parts.**  
Alphabetize: the **t** of tert-butyl  
before the **m** of methyl  
**Answer: 4-tert-butyl-3-methylpentane**

Problem 4.7 Give the IUPAC name for each compound.

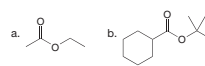


### How To's

How To's provide students with detailed instructions on how to work through key processes.

#### How To Name an Ester (RCO<sub>2</sub>R') Using the IUPAC System

**Example** Give a systematic name for each ester:



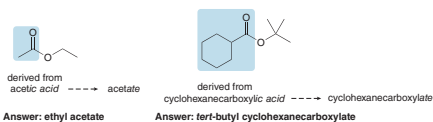
**Step [1]** Name the R' group bonded to the oxygen atom as an alkyl group.

- The name of the alkyl group, ending in the suffix *-yl*, becomes the **first** part of the ester name.



**Step [2]** Name the acyl group (RCO-) by changing the *-ic acid* ending of the parent carboxylic acid to the suffix *-ate*.

- The name of the acyl group becomes the **second** part of the name.



## Applications and Summaries

### Key Concept Summaries

Succinct summary tables reinforcing important principles and concepts are provided at the end of each chapter.

### Margin Notes

Margin notes are placed carefully throughout the chapters, providing interesting information relating to topics covered in the text. Some margin notes are illustrated with photos to make the chemistry more relevant.



All soaps are salts of fatty acids. The main difference between soaps is the addition of other ingredients that do not alter their cleaning properties: dyes for color, scents for a pleasing odor, and oils for lubrication. Soaps that float are aerated, so that they are less dense than water.

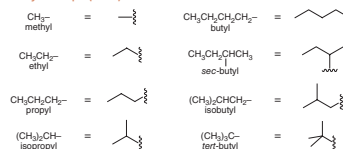
#### KEY CONCEPTS

##### Alkanes

##### General Facts About Alkanes (4.1–4.3)

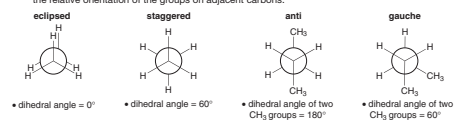
- Alkanes are composed of **tetrahedral**,  $sp^3$  hybridized C atoms.
- There are two types of alkanes: acyclic alkanes having molecular formula  $C_nH_{2n+2}$  and cycloalkanes having molecular formula  $C_nH_{2n}$ .
- Alkanes have only **nonpolar C–C and C–H bonds** and no functional group, so they undergo few reactions.
- Alkanes are named with the suffix **-ane**.

##### Names of Alkyl Groups (4.4A)



##### Conformations in Acyclic Alkanes (4.9, 4.10)

- Alkane conformations can be classified as **eclipsed**, **staggered**, **anti**, or **gauche** depending on the relative orientation of the groups on adjacent carbons.



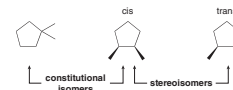
- A staggered conformation is **lower in energy** than an eclipsed conformation.
- An anti conformation is **lower in energy** than a gauche conformation.

##### Types of Strain

- Torsional strain**—an increase in energy caused by eclipsing interactions (4.9).
- Steric strain**—an increase in energy when atoms are forced too close to each other (4.10).
- Angle strain**—an increase in energy when tetrahedral bond angles deviate from 109.5° (4.11).

##### Two Types of Isomers

- Constitutional isomers**—isomers that differ in the way the atoms are connected to each other (4.1A).
- Stereoisomers**—isomers that differ only in the way the atoms are oriented in space (4.13B).





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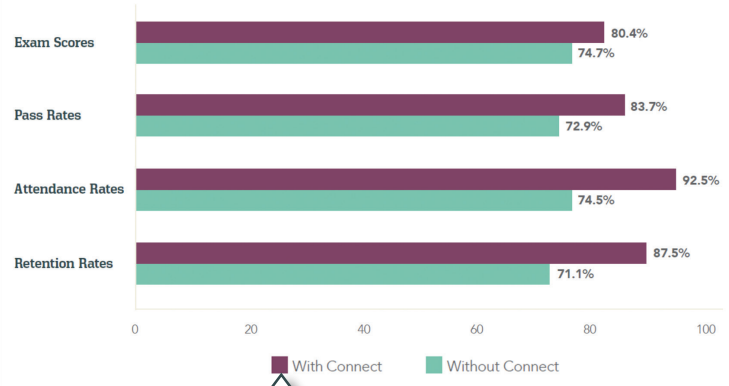


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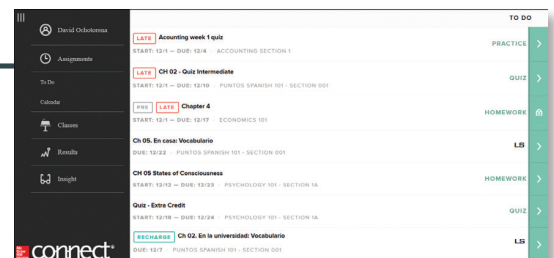


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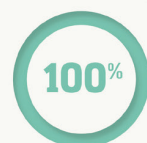
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Within the Instructor's Presentation Tools, instructors have access to editable PowerPoint lecture outlines, which appear as ready-made presentations that combine art and lecture notes for each chapter of the text. For instructors who prefer to create their lecture notes from scratch, all illustrations, photos, tables, *How To's*, and Sample Problems are pre-inserted by chapter into a separate set of PowerPoint slides. They are also available as individual .jpg files.

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- **Animations** Full-color animations illustrating important processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.

### Student Study Guide/Solutions Manual

Written by Janice Gorzynski Smith and Erin R. Smith, the Student Study Guide/Solutions Manual provides step-by-step solutions to all in-chapter and end-of-chapter problems. Each chapter begins with an overview of key concepts and includes a short-answer practice test on the fundamental principles and new reactions.

# Acknowledgments

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Steven Castle, *Brigham Young University*  
Ihsan Erden, *San Francisco State University*  
Andrew Frazer, *University of Central Florida, Orlando*  
Tiffany Gierasch, *University of Maryland, Baltimore County*  
Anne Gorden, *Auburn University*  
Michael Lewis, *Saint Louis University*  
Eugene A. Mash, Jr., *University of Arizona*  
Mark McMills, *Ohio University*  
Joan Mutanyatta-Comar, *Georgia State University*  
Felix Ngassa, *Grand Valley State University*  
Michael Rathke, *Michigan State University*  
Jacob Schroeder, *Clemson University*  
Keith Schwartz, *Portland State University*  
John Selegue, *University of Kentucky*  
Paul J. Toscano, *University at Albany, SUNY*  
Jane E. Wissinger, *University of Minnesota*

The following contributed to the editorial direction of *Organic Chemistry*, fifth edition, by responding to our survey on the MCAT and the organic chemistry course student population:

Chris Abelt, *College of William and Mary*  
Orlando Acevedo, *Auburn University*  
Kim Albizati, *University of California, San Diego*  
Merritt Andrus, *Brigham Young University*  
Ardeshir Azadnia, *Michigan State University*  
Susan Bane, *Binghamton University*  
Russell Barrows, *Metropolitan State University of Denver*  
Peter Beak, *University of Illinois, Urbana—Champaign*  
Phil Beauchamp, *Cal Poly, Pomona*  
Michael Berg, *Virginia Tech*  
K. Darrell Berlin, *Oklahoma State University*  
Thomas Bertolini, *University of South Carolina*  
Ned Bowden, *University of Iowa*  
David W. Brown, *Florida Gulf Coast University*  
Rebecca Broyer, *University of Southern California*  
Arthur Bull, *Oakland University*  
K. Nolan Carter, *University of Central Arkansas*  
Steven Castle, *Brigham Young University*  
Victor Cesare, *St. John's University*  
Manashi Chatterjee, *University of Nebraska, Lincoln*  
Melissa Cichowicz, *West Chester University*

Jeff Corkill, *Eastern Washington University, Cheney*  
Sulekha Coticone, *Florida Gulf Coast University*  
Michael Crimmins, *University of North Carolina at Chapel Hill*  
Eric Crumpler, *Valencia College*  
David Dalton, *Temple University*  
Rick Danheiser, *Massachusetts Institute of Technology*  
Tammy Davidson, *University of Florida*  
Brenton DeBoef, *University of Rhode Island*  
Amy Deveau, *University of New England*  
Kenneth M. Doxsee, *University of Oregon*  
Larissa D'Souza, *Johns Hopkins University*  
Philip Egan, *Texas A&M University, Corpus Christi*  
Seth Elsheimer, *University of Central Florida*  
John Esteb, *Butler University*  
Steve Fleming, *Temple University*  
Marion Franks, *North Carolina A&T State University*  
Andy Frazer, *University of Central Florida*  
Brian Ganley, *University of Missouri, Columbia*  
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Anne Gorden, *Auburn University*  
Carlos G. Gutierrez, *California State University, Los Angeles*  
Scott Handy, *Middle Tennessee State University*  
Rick Heldrich, *College of Charleston*  
James Herndon, *New Mexico State University*  
Kathleen Hess, *Brown University*  
Sean Hickey, *University of New Orleans*  
Carl Hoeger, *University of California, San Diego*  
Javier Horta, *University of Massachusetts, Lowell*  
Bob A. Howell, *Central Michigan University*  
Jennifer Irvin, *Texas State University*  
Phil Janowicz, *Cal State, Fullerton*  
Mohammad Karim, *Tennessee State University*  
Mark L. Kearley, *Florida State University*  
Amy Keirstead, *University of New England*  
Margaret Kerr, *Worcester State University*  
James Kiddle, *Western Michigan University*  
Jisook Kim, *University of Tennessee at Chattanooga*  
Angela King, *Wake Forest University*  
Margaret Kline, *Santa Monica College*  
Dalila G. Kovacs, *Grand Valley State University*  
Deborah Lieberman, *University of Cincinnati*  
Carl Lovely, *University of Texas, Arlington*  
Kristina Mack, *Grand Valley State University*  
Daniel Macks, *Towson University*  
Vivian Mativo, *Georgia Perimeter College, Clarkston*  
Mark McMills, *Ohio University*  
Stephen Mills, *Xavier University*  
Robert Minto, *Indiana University–Purdue University, Indianapolis*  
Debbie Mohler, *James Madison University*  
Kathleen Morgan, *Xavier University of Louisiana*  
Paul Morgan, *Butler University*  
James C. Morris, *Georgia Institute of Technology*

Linda Munchausen, *Southeastern Louisiana University*  
Toby Nelson, *Oklahoma State University*  
Felix Ngassa, *Grand Valley State University*  
George A. O'Doherty, *Northeastern University*  
Anne Padias, *University of Arizona*  
Dan Paschal, *Georgia Perimeter College*  
Richard Pennington, *Georgia Gwinnett College*  
John Pollard, *University of Arizona*  
Gloria Proni, *John Jay College*  
Khalilah Reddie, *University of Massachusetts, Lowell*  
Joel M. Ressler, *West Chester University of Pennsylvania*  
Christine Rich, *University of Louisville*  
Carmelo Rizzo, *Vanderbilt University*  
Harold R. Rogers, *California State University, Fullerton*  
Paul B. Savage, *Brigham Young University*  
Deborah Schwyter, *Santa Monica College*  
Holly Sebahar, *University of Utah*  
Laura Serbulea, *University of Virginia*  
Abid Shaikh, *Georgia Southern University*  
Kevin Shaughnessy, *The University of Alabama*  
Joel Shulman, *University of Cincinnati*  
Joseph M. Simard, *University of New England*  
Rhett Smith, *Clemson University*  
Priyantha Sugathapala, *University at Albany, SUNY*  
Claudia Taenzler, *University of Texas at Dallas*  
Robin Tanke, *University of Wisconsin, Stevens Point*  
Richard T. Taylor, *Miami University, Oxford*  
Edward Turos, *University of South Florida*  
Ted Wood, *Pierce College*  
Kana Yamamoto, *University of Toledo*

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Although every effort has been made to make this text and its accompanying Student Study Guide/Solutions Manual as error-free as possible, some errors undoubtedly remain. Please feel free to email one of the authors about any inaccuracies, so that subsequent editions may be further improved.

With much aloha,

Janice Gorzynski Smith  
[jgsmith@hawaii.edu](mailto:jgsmith@hawaii.edu)

Heidi R. Vollmer–Snarr  
[hrvsnarr@stanford.edu](mailto:hrvsnarr@stanford.edu)



# List of *How To's*

*How To* boxes provide detailed instructions for key procedures that students need to master. Below is a list of each *How To* and where it is presented in the text.

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# List of Mechanisms

Mechanisms are the key to understanding the reactions of organic chemistry. For this reason, great care has been given to present mechanisms in a detailed, step-by-step fashion. The list below indicates when each mechanism in the text is presented for the first time.

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# List of Selected Applications

Applications make any subject seem more relevant and interesting—for nonmajors and majors alike. The following is a list of the biological, medicinal, and environmental applications that have been integrated throughout *Organic Chemistry with Biological Topics*. Each chapter opener showcases an interesting and current application relating to the chapter's topic. (Code: G = general; M = medicinal; B = biological; E = environmental)

## Prologue

- G Methane, the main component of natural gas
- G Ethanol, the alcohol in beverages
- E Trichlorofluoromethane, a CFC responsible for destroying the stratospheric ozone layer
- M Amoxicillin, a widely used antibiotic
- M Fluoxetine, the antidepressant Prozac
- M AZT, a drug used to treat HIV
- M Capsaicin, a compound found in topical pain relief creams
- E DDT, a nonspecific pesticide that persists in the environment
- M The antimalarial drugs quinine, chloroquine, and artemisinin

## Chapter 1 Structure and Bonding

- M L-Dopa, a drug used to treat Parkinson's disease (Chapter opener and Section 1.14)
- M Alendronic acid (Fosamax), a drug used to prevent osteoporosis (Section 1.5)
- B Enanthotoxin, a poisonous compound isolated from hemlock water dropwort (Section 1.7)
- G Vanillin, the principal component in the extract of the vanilla bean (Section 1.8B)
- M Structures of active ingredients in common sunscreens (Section 1.8B)
- G Ethane, a component of natural gas (Section 1.10A)
- G Ethylene, a hydrocarbon used to make the plastic polyethylene (Section 1.10B)
- G Acetylene, a gas used in welding torches (Section 1.10C)
- G Cucumber aldehyde, the compound responsible for the odor of freshly cut cucumbers (Section 1.10C)
- M Sinemet, a drug used to treat Parkinson's disease that combines L-dopa and carbidopa (Section 1.14)
- B Vitamin B<sub>6</sub> (Section 1.14)

## Chapter 2 Acids and Bases

- M Aspirin, a common analgesic and antipyretic (Chapter opener and Section 2.7)
- M The acid–base chemistry of morphine (Section 2.1)
- M The nasal decongestant pseudoephedrine (Section 2.5, Problem 2.17)
- M Glycolic acid, an  $\alpha$ -hydroxy acid used in skin care products (Section 2.5, Problem 2.20)
- E Sulfuric acid, a major contributor to acid rain (Section 2.6)
- M Salicin, an analgesic found in willow bark (Section 2.7)

## Chapter 3 Introduction to Organic Molecules and Functional Groups

- B Vitamin C, a water-soluble vitamin that is important in the formation of collagen (Chapter opener and Section 3.5B)
- E Hemibrevetoxin B, a neurotoxin produced by algal blooms (“red tides”) (Section 3.2B)
- M Diethyl ether, the first common general anesthetic (Section 3.2B)
- B Sucrose and the antibiotic amoxicillin (Section 3.2B, Problem 3.3)
- M Dexamethasone, a synthetic steroid (Section 3.2B, Problem 3.5)
- B Spermine, isolated from semen, and meperidine, the narcotic Demerol (Section 3.2B, Problem 3.6)
- M The anticancer agent doxorubicin (Adriamycin) (Section 3.2B, Problem 3.7)
- M Thyrotropin-releasing hormone (Section 3.2C, Problem 3.8)
- M Tamiflu, an antiviral drug used to treat influenza (Section 3.2C, Problem 3.9)
- B Pyruvic acid, lipoic acid, and folic acid as examples of biological molecules with multiple functional groups (Section 3.2C, Problem 3.10)
- B Biological phosphorus compounds (Section 3.2D)
- G How geckos use van der Waals forces to stick to walls (Section 3.3B)
- B Ionic, water-soluble biological compounds: isopentenyl diphosphate and acetylcholine (Section 3.4C)
- G MTBE, a high-octane additive in unleaded gasoline, and 4,4'-dichlorobiphenyl, a PCB (Section 3.4C)
- B Phenylalanine and 11-*cis*-retinal (Section 3.4C, Sample Problem 3.4)

- B Adrenaline and estrone (Section 3.4C, Problem 3.17)
- B Progesterone and testosterone (Section 3.4C, Sample Problem 3.5)
- B Norethindrone, an oral contraceptive, and arachidonic acid, a fatty acid (Section 3.4C, Problem 3.18)
- B Vitamin A (retinol), a fat-soluble vitamin found in the vision receptors of the eyes (Section 3.5A)
- B  $\beta$ -Carotene, a precursor to vitamin A (Section 3.5A)
- B Vitamin B<sub>3</sub> and vitamin K<sub>1</sub> (Section 3.5B, Problem 3.19)
- B Avocados as a source of pantothenic acid, vitamin B<sub>5</sub> (Section 3.5B, Problem 3.20)
- M Morphine and heroin (Section 3.7A, Problem 3.23)
- M The antibiotics nonactin and valinomycin (Section 3.7B)
- B The reactive features of isopentenyl diphosphate and pyruvic acid (Section 3.8)
- B The nucleophilic thiol of coenzyme A (Section 3.8)
- B Methionine, ATP, and *S*-adenosylmethionine (Section 3.8, Problem 3.28)
- B Amino acids and proteins (Section 3.9A)
- B Monosaccharides and carbohydrates (Section 3.9B)
- B Nucleotides and nucleic acids (Section 3.9C)
- B Lipids (Section 3.9D)
- M, B End-of-chapter problems: 3.33–3.35, 3.37, 3.38, 3.40, 3.48–3.57, 3.60, 3.61, 3.63–3.65, and 3.67

#### Chapter 4 Alkanes

- E Oil slicks that result from crude petroleum being spilled into the ocean from oil tankers or oil wells (Chapter opener)
- B The cockroach pheromone undecane (Section 4.1)
- B Cyclohexane, one component of mangoes (Section 4.1)
- B Allicin, a compound responsible for the odor of garlic (Section 4.3)
- M Systematic names, generic names, and trade names in over-the-counter drugs like Motrin (Section 4.3)
- G Fossil fuels such as natural gas and petroleum (Section 4.7)
- E The combustion of alkanes and how it contributes to climate change (Section 4.14B)
- B Lipids such as fat-soluble vitamins, phospholipids, waxes, prostaglandins, and steroids (Section 4.15)
- B Pristane, a high molecular weight alkane found in shark liver oil (Section 4.15, Problem 4.33)
- B End-of-chapter problems: 4.66 and 4.69

#### Chapter 5 Stereochemistry

- M, B Paclitaxel (Taxol), a drug used to treat ovarian, breast, and other cancers (Chapter opener)
- B How differences in the three-dimensional structure of starch and cellulose affect their shape and function (Section 5.1)
- M, B Identifying stereogenic centers in Darvon (an analgesic), ephedrine (a decongestant), and fructose (a simple sugar) (Section 5.4A)
- M The three-dimensional structure of thalidomide, an anti-nausea drug that caused catastrophic birth defects (Section 5.5)
- M, B Identifying stereogenic centers in paclitaxel (anticancer agent) and sucrose (Section 5.5)
- M Identifying stereogenic centers in gabapentin (a drug used to treat seizures and chronic pain), gabapentin enacarbil, cholesterol, and Zocor (cholesterol-lowering drug) (Section 5.5, Problems 5.9 and 5.10)
- M Assigning *R* and *S* configurations in the drugs Plavix and Zestril (Section 5.6, Problems 5.14 and 5.15)
- B The sweetener sorbitol (Section 5.9, Problem 5.24)
- B The specific rotation of MSG, a common flavor enhancer (Section 5.12D, Problem 5.32)
- M Chiral drugs and how mirror image isomers can have drastically different properties—the analgesic ibuprofen, the antidepressant fluoxetine, and the anti-inflammatory agent naproxen (Section 5.13A)
- B The sense of smell and how mirror image isomers (e.g., carvone and celery ketone) can smell different (Section 5.13B and Problem 5.35)
- M, B End-of-chapter problems: 5.36, 5.43, 5.49, 5.50, 5.53, 5.55, 5.60, and 5.65–5.71

#### Chapter 6 Understanding Organic Reactions

- B Entropy changes in the metabolism of glucose (Chapter opener and Section 6.4)
- B A biological substitution reaction: the hydrolysis of a triacylglycerol to glycerol + fatty acids (Section 6.2A)
- B A biological elimination reaction in the citric acid cycle (Section 6.2B)
- B A biological addition reaction with a thioester, a key step in fatty acid metabolism (Section 6.2C)
- B Four enzyme-catalyzed steps in the citric acid cycle (Section 6.2C, Problem 6.2)
- B The air oxidation of vegetable oils (Section 6.3C, Sample Problem 6.1)
- B Examples of exothermic reactions: the hydrolysis of ATP and the oxidation of glucose (Section 6.4)
- B Coupled reactions in metabolism (Section 6.5C)
- G The reaction of gasoline with O<sub>2</sub> (Section 6.9A)
- G Refrigeration and spoilage (Section 6.9A)
- B Enzymes, biological catalysts (Section 6.11)
- B End-of-chapter problems: 6.27, 6.28, 6.32, 6.39, 6.41, 6.52, and 6.56