DAT Organic Chemistry Rapid Learning Series – Course GuideBook

RapidLearningCenter.com
Chemistry : Biology : Physics : Math

COURSE TABLE OF CONTENTS – TOPICAL SUMMARY

Core Unit #1 – Foundation of DAT Organic Chemistry

Tutorial 01: Introduction to DAT Organic Chemistry

- Dental Admissions Test
- Computer based test format of the DAT
- The DAT Natural Sciences focus areas
- DAT Organic Chemistry comprehension areas
- Test-preparation strategies
- Test-taking strategies
- How to attack and solve Organic Chemistry problems

Tutorial 02: Chemistry Review: Structure and Bonding

- Atomic and Molecular Structure
- Molecular Shape
- Types of Carbon Molecules
- Intramolecular Bond Interactions
- Molecular Orbitals
- Resonance
- Intermolecular Forces

Core Unit #2 – Nomenclature

Tutorial 03: IUPAC Rules – Organic Nomenclature I

- IUPAC Nomenclature
  - Parent chain
  - Alkyl prefixes
  - Substituents
  - Numerical prefixes
  - Halogen prefixes
  - Rules used in naming compounds
- Common Nomenclature
  - Classification of carbons
  - Rules used in naming compounds

Tutorial 04: IUPAC Rules – Organic Nomenclature II

- IUPAC Nomenclature
  - Rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, and amines
  - Rules for naming carboxylic acid derivatives
- Common Nomenclature
  - Rules for naming alcohols, ethers, ketones, and amines

Tutorial 05: Drawing Organic Structures

- Importance of Drawing Structures
- Types of Structures
- Isomers
- Abbreviations

Tutorial 06: Functional Groups of Organic Compounds

- The chemistry of carbon
- Functional Groups
- Acids and Bases
- Electron Pushing

Core Unit #3 – Stereochemistry and Conformation

Tutorial 07: Stereochemistry

- Isomers
  - Constitutional isomers
  - Stereoisomers
  - Conformational isomers
- Basic Concepts of Stereochemistry
  - Stereochemistry overview
  - Chirality
- Stereoisomers
  - Enantiomers
  - Diastereomers
- Assigning R and S Configurations to Chiral Centers
  - Distinguishing enantiomers pairs by assigning their R and S configurations
  - Assigning the absolute configuration to chiral compounds
  - Meso compounds
- Stereoisomers of Alkenes
  - Relative configuration
  - Absolute configuration

Tutorial 08: Conformational Analysis

- Basic Concepts
- Conformations of Ethane
- Conformations of Butane
- Bond Angles of Cycloalkanes
- Conformations of Cyclohexane

Core Unit #4 – Hydrocarbons and Reactions

Tutorial 09: Saturated Hydrocarbons

- Definitions
  - Hydrocarbons
  - Alkanes
  - Cycloalkanes
  - Alkyl halides
- Properties and Uses of Alkanes and Cycloalkanes
  - Properties
  - Structure and conformations
  - Uses
- Properties and Uses of Alkyl Halides
  - Properties
  - Uses

- Alkane and Cycloalkane Nomenclature
  - IUPAC nomenclature
  - Common nomenclature
- Nomenclature of Alkyl Halides
  - IUPAC nomenclature
  - Common nomenclature
- Reactions of Alkanes
  - Combustion
  - Cracking
  - Halogenation

Tutorial 10: Unsaturated Hydrocarbons

- Background Information for Alkenes, Alkynes, and Dienes
- Nomenclature of Alkenes, Alkynes, and Dienes
- Synthesis of Alkenes
- Synthesis of Alkynes
- Reactions of Alkenes
- Reactions of Alkynes
- Polymerization of Alkenes
- Oxidation of Alkenes and Alkynes

Core Unit #5 – Aromatics

Tutorial 11: Aromatic Compounds and Aromaticity

- Background Information for Aromatic Compounds
- Nomenclature of Aromatic Compounds
- Reactions of Aromatic Compounds

Core Unit #6 – Functional Groups and Reactions

Tutorial 12: Alcohols and Ethers

- Background Information for Alcohols and Ethers
  - Definitions
  - Properties
  - Uses
  - Classification of alcohols
- Nomenclature for Alcohols and Ethers
  - IUPAC nomenclature
  - Common nomenclature
- Physical Properties of Alcohols
  - Hydrogen bonding
  - Boiling points of alcohols
  - Water solubility of alcohols
  - Acidity of alcohols
- Synthesis of Alcohols
  - From alkenes
  - From alkyl halides
  - From organometallic reagents reacting with aldehydes and ketones
  - From reduction of aldehydes and ketones

Tutorial 13: Aldehydes and Ketones

Tutorial 14: Carboxylic Acids

  - Oxidation of primary alcohols
  - Oxidation of aldehydes
  - Carboxylation of Grignard reagents
  - Hydrolysis of nitriles
- Reactions of Carboxylic Acids
  - Reduction to primary alcohols
  - Conversion to acid halides
  - Esterification
  - Conversion to anhydrides
  - Decarboxylation

Tutorial 15: Acid Derivatives

- Background Information for Acid Derivatives
  - Shape
  - Properties
  - Relative reactivity of acid derivatives
- Nomenclature of Acid Derivatives
  - Rules for acid halides
  - Rules for esters
  - Rules for anhydrides
  - Rules for amides
- Reactions of Acid Halides
  - Hydrolysis
  - Conversion to esters
  - Conversion to amides
  - Reduction to alcohols
  - Reduction to aldehydes
  - Conversion to ketones
- Reactions of Esters
  - Hydrolysis
  - Saponification
  - Transesterification
  - Reduction to alcohols
  - Conversion to amides
- Reactions of Anhydrides
  - Hydrolysis
  - Conversion to esters
  - Conversion to amides
- Reactions of Amides
  - Hydrolysis
  - Hofmann Rearrangement
  - Reduction to amines
  - Dehydration

Tutorial 16: Keto Acids and Esters

- Background Information for Keto Acids and Esters
  - Definitions
  - Nomenclature
  - Acidity of the α-hydrogen
  - Keto-enol tautomerism
- Reactions of Keto Acids and Esters
  - Decarboxylation

- Acetoacetic acid synthesis

Tutorial 17: Amines

- Background Information for Amines
  - Classification of amines
  - Shape
  - Properties
  - Uses
- Nomenclature of Amines
  - IUPAC nomenclature
  - Common nomenclature
  - Amine salts
- Synthesis of Amines
  - Reduction of nitro compounds
  - Reduction of nitriles
  - Reduction of amides
  - Alkylation of amines
  - Reductive amination of aldehydes and ketones
- Reactions of Amines
  - Reaction with alkyl halides
  - Reaction with aldehydes and ketones
  - Acylation
  - Reaction with sulfonyl chlorides
  - Hofmann elimination
  - Reaction with nitrous acid

Core Unit #7 – Organic Analysis and Separation

Tutorial 18: Infrared and UN Spectroscopy

- Basic Information for Infrared
  - Background
  - Intensity of infrared absorptions
  - Bonds with similar infrared absorptions
  - Molecular vibrations
  - Index of hydrogen deficiency
  - Functional groups
- Infrared Interpretation Trends
  - Zones
  - By functional groups
- Infrared Absorption Frequency Tables
  - Abbreviations
  - Frequencies
- Infrared Spectra Problem Solving
  - Steps
  - Examples
- Basics of UV/Vis Spectroscopy
  - Theory of UV/Vis spectroscopy
  - Absorption of UV/Vis light
  - Conjugation

Tutorial 19: NMR and Mass Spectrometry

Core Unit #8 – Individual Reactions, Multistep Reactions and Mechanisms

Tutorial 21: Organic Reactions

- Terminology of Organic Reactions
  - Mechanism, stoichiometry, thermodynamics, kinetics
  - Transition state, activation energy, Hammond postulate
  - Kinetic versus thermodynamic control, reactive intermediate, catalyst, solvent effect
- Reactions of Alkyl Halides
  - Substitution with nucleophiles to form other compounds
  - Elimination with KOH to form alkenes
  - Reaction with lithium to form alkyl lithiums
  - Reaction with magnesium to form Grignard reagents
- Reactions of Alkenes
  - Addition of HX to form alkyl halides
  - Addition of H_2O to form alcohols
  - Addition of X_2 to form dihaloalkanes
  - Addition of hydrogen to form alkanes
  - Oxidation with $KMnO_4$ to form diols
  - Oxidation with O_3 to form aldehydes and ketones
- Reactions of Alkynes
  - Addition of 2 HX to give dihaloalkanes
  - Addition of 2 X_2 to give tetrahaloalkanes
  - Addition with 2 H_2 to give alkanes
  - Oxidation with $KMnO_4$ to give diketones
  - Oxidation with O_3 to give carboxylic acids
- Reactions of Aromatic Compounds
- Reaction with X_2 and catalyst to give ArX
  - Reaction with HNO_3 and H_2SO_4 to give $ArNO_2$
  - Reaction with SO_3 and H_2SO_4 to give $ArSO_3H$
  - Reaction with RX and $AlCl_3$ to give ArR
  - Reaction with R(C=O)X and $AlCl_3$ to give ketones
- Reactions of Amines
  - Reaction with RX, followed by lost of HX, to yield larger amines
  - Reaction with HX, to yield ammonium salts
  - Reaction with acid halides to yield amides
  - Reaction with sulfonyl chlorides to yield sulfonamides
- Reactions of Alcohols
  - Reaction with metals to yield alkoxide ions
  - Reaction with HX, PX_3, or $POCl_3$ to yield RX
  - Reaction with heat and acid to yield alkenes
  - Dihalides are treated with 2 KOH to yield alkynes
  - Oxidation
  - Reaction with RCOOH and acid to yield esters
- Reactions of Aldehydes and Ketones
  - Reduction to alcohols
  - Reduction to alkanes
  - Reaction with organometallic reagents to form alcohols
  - Reaction with primary amines to yield imines
  - Reductive amination to yield amines
  - Oxidation of aldehydes to carboxylic acids

- Reactions of Carboxylic Acids
  - Reduction to alcohols
  - Reaction with thionyl chloride to yield acid chlorides
  - Reaction with alcohols and acid to give esters
  - Reaction with acid halides to give anhydrides
- Reactions of Acid Halides
  - Hydrolysis to form carboxylic acids
  - Reaction with alcohols to form esters
  - Reaction with amines to form amides
  - Reduction to alcohols
  - Reduction to aldehydes
  - Reaction with R_2CuLi to form ketones
- Reactions of Esters
  - Reaction with water and acid to yield carboxylic acids and alcohols
  - Reduction to alcohols
  - Reaction with amines to yield amides and alcohols
- Reactions of Anhydrides
  - Hydrolysis of anhydrides to yield carboxylic acids
  - Reaction with alcohols to yield esters and carboxylic acids
  - Reaction with amines to yield amides and carboxylic acids
- Reactions of Amides
  - Reaction with aqueous acid to yield carboxylic acids and ammonium ions
  - Reaction with water and hydroxide ion to yield carboxylate anions and amines
  - Reduction to amines
  - Dehydration to nitriles

Tutorial 22: Synthesis, Multistep and Retrosynthesis

- Principles of Synthesis
  - Definition of synthesis
  - Total synthesis
  - Methodology
- Retrosynthesis
  - Retrosynthetic analysis
  - Disconnections
  - Evaluation

Tutorial 23: Organic Reaction Mechanisms

- Terminology in Mechanisms
  - Double headed arrows, heterolytic bond cleavage, heterogenic bond formation
  - Single headed arrows, homolytic bond cleavage, homogenic bond formation
  - Polar reactions
- Substitution Reactions
  - Sn1 reactions
  - Sn2 reactions
- Elimination Reactions
  - E1 reactions
  - E2 reactions
- Mechanism of Addition Reactions
  - Mechanism for the addition of HX to alkenes
  - Mechanism for addition of halogens to alkenes
- Nucleophilic Addition to Carbonyl Compounds
  - Reaction of a Grignard reagent with aldehydes

- Reaction of aldehydes with primary amines
- Electrophilic Aromatic Substitution
  - Mechanism of electrophilic aromatic substitution
  - Example
- Acid-Base Reactions
  - Deprotonation
  - Protonation
- Carbocation Mechanisms
  - 1,2-Hydride shift
  - 1,2-Alkyl shift
- Anion Mechanisms
  - Mechanism for the alkylation of carbonyl compounds with LDA
  - Mechanism for the addition of the hydride ion
- Radical Reactions
  - Halogenation of alkenes
- Mechanism Basics
  - Understanding mechanisms
- Arrow Drawing Skills
  - Basic arrow drawing skills for heterolytic bonds
  - Examples of nucleophiles
  - Basic arrow drawing skills for homolytic bonds
- Movement of Electrons with Arrows
  - An unshared electron pair becomes a shared electron pair
  - A shared electron pair becomes an unshared electron pair
  - A shared electron pair becomes another shared electron pair
- Intermediates
  - Formation of intermediates
  - Characteristics of good intermediates
  - Characteristics of unlikely intermediates

Core Unit #9 – Acids and Bases

Tutorial 24: Acid-Base Chemistry

- Definitions of acids and bases
  - Arrhenius acids and bases
  - Brønsted-Lowry Theory
  - Lewis acids and bases
- Conjugate acids and bases
- Equilibria in acid-base reactions
- Molecular structure considerations
  - Resonance in acid-base chemistry
  - Inductive effects

COURSE FEATURES

This tutorial series is a carefully selected collection of core concept topics that cover the essential concepts. It consists of three parts:

1. Concept Tutorials – 24 essential topics
2. Problem-Solving Drills – 24 practice sets
3. Super Condense Cheat Sheets – 24 super review sheets

Core Tutorials

+ Self-contained tutorials…not an outline of information which would need to be supplemented by an instructor.
+ Concept map showing inter-connections of new concepts in this tutorial and those previously introduced.
+ Definition slides introduce terms as they are needed.
+ Visual representation of concepts.
+Conceptual explanation of important properties and problem solving techniques
+ Animated examples of processes and cycles in human physiology.
+ A concise summary is given at the conclusion of the tutorial.

Problem Solving Drills

Each tutorial has an accompanying Problem Set with 10 problems covering the material presented in the tutorial. The problem set affords the opportunity to practice what has been learned.

Condensed Cheat Sheet

Each tutorial has a one-page cheat sheet that summarizes the key concepts and vocabularies and structures presented in the tutorial. Use the cheat sheet as a study guide after completing the tutorial to re-enforce concepts and again before an exam.

Chapter by Chapter Detailed Content Descriptions

01: Introduction to DAT Organic Chemistry

Chapter Summary

In this first tutorial, we will give you the introduction to the test you are about to take. In particularly, you will learn more about this DAT Organic Chemistry course and get ready for the extensive coverage on required knowledge in the chemistry section of biological survey subtest. The DAT and CBT are defined and the scope of the organic chemistry section is introduced. The test-prep and test-taking strategies are also discussed. Finally, the tips in how to solve chemistry problems are described.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Dental Admissions Test
Computer based test format of the DAT
The DAT Natural Sciences focus areas
DAT Organic Chemistry comprehension areas
Test-preparation strategies
Test-taking strategies
How to attack and solve Organic Chemistry problems

Chapter Review

DAT - The DAT is the Dental College Admissions Test by American Dental Association (ADA). Its computer based test is a standardized exam that most US and Canadian dental schools require in order to consider a student for admission.
DAT Organic Chemistry - The science section of the DAT consists of 100 items that includes questions about: General Chemistry, Organic Chemistry and Biology. Organic Chemistry usually consists of about 30 items broken down as shown with the numbers representing the number of items usually tested within each focus area.
Test -Prep Strategies: (1) Smart Time Management (2) Key Concept Mastery (3) Practice-Practice-Practice (4) Systematic Review
Test-Taking Strategies: (1) Know the Test (2) Plan Your Attack (3) Build Focus (4) Zoom In On The Answer (5) Guess The Right Way
Organic Chemistry Problem Solving: (1) Think of the answer before scanning the answer choices (2) Beware of the familiar (3) Aware of the Absolute (4) Deal with the

Similar and Opposites (5) Know about the elimination and answer selection (6) Make educated guesses.

02: Chemistry Review – Structure and Bonding

Chapter Summary

Organic chemistry is the study of carbon compounds. In order to learn more about carbon compounds, and the reactions they undergo, one must understand some basic, underlying principles of chemistry first. It is essential to have a firm grasp of concepts like atomic structure, molecular orbitals, intra- and intermolecular interactions, and resonance. With these basic concepts as the foundation, learning about organic compounds and how they react will be much easier.

Tutorial Features

- Definition slides introduce terms as they are needed.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of concepts.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

- Atomic and Molecular Structure
    - Atomic structure
    - Electronic configuration
    - Valence electrons
    - Isotopes, ions and radicals
    - Lewis structures
    - Formal charges
- Molecular Shape
    - VSEPR (valence shell electron pair repulsion) theory
    - Predicting molecular shape
    - Structural formulas of heteroatoms
- Types of Carbon Molecules
    - Stable, neutral molecules
    - Carbanions
    - Carbocations
    - Radicals
- Intramolecular Bond Interactions
    - Electronegativity
    - Bond polarity
    - Bonding
    - Bond breaking
- Molecular Orbitals
    - Sigma and pi bonds
    - Hybridization
- Resonance
    - Theory of resonance
    - Delocalized electrons

Intermolecular Forces
- London Dispersion forces
- Dipole-dipole forces
- Hydrogen bonding

Chapter Review

Atomic Number
The number of protons in an atom.

Electronic Configuration
The arrangement of an atom or ion's electrons into atomic orbitals. There are four types of atomic orbitals: s orbitals (maximum of 2 electrons), p orbitals (maximum of 6 electrons), d orbitals (maximum of 10 electrons), and f orbitals (maximum of 14 electrons).

Valence Electrons
The electrons that comprise the outer shell of an atom and are typically the electrons involved in bonding.

Isotope
An atom having the same number of protons in its nucleus as other varieties of the element but has a different number of neutrons.

Ion
An atom or group of atoms that has either lost or gain an electron(s) resulting in a charged species.

Radical
An atomic or molecular species with an unpaired electron.

Formal Charge
The charge that an atom would have if the bonding electrons in every bond to it were equally shared. Formal charges are useful for accounting for the electrons in a molecule, but they do not have any intrinsic physical meaning. The equation used to determine the formal charge of an atom(s) is below:

Formal charge = [number of valence electrons] – [nonbonding electrons] – ½[bonding electrons]

Lewis Structures
Diagrams that show the bonding between atoms of a covalently bonded molecule and any lone pairs of electrons that may exist in the molecule. Lewis structures are drawn using only the valence electrons.

VSEPR Theory
Valence shell electron pair repulsion theory (VSEPR) is a model in chemistry that attempts to predict the shape of a molecule based on the valence electrons of a molecule. The theory states that the areas of electron density in a molecule will repel each other, and in doing so, adopt regular, predictable shapes.

Carbanion

A molecule that contains a carbon which has gained a pair of electrons and is negatively charged.

Carbocation
A molecule that contains a carbon which has lost a pair of electrons and is positively charged.

Carbon Radical
A carbon that is neutral and possesses a single, unpaired electron.

Stable, Neutral Carbon Compound
A compound that has not lost or gained any electrons.

Electronegativity
The ability of an atom to attract electrons.

Dipole
The separation of charge between two covalently bonded atoms.

Intramolecular Bond Interactions
Bonding interactions within a molecule.

Ionic Bonding
Type of intramolecular bonding interaction that involves the actual transfer of electrons from one atom to another.

Covalent Bonding
Type of intramolecular bonding interaction that involves the sharing of electrons between atoms. The difference in electronegativity, as well as other factors, between atoms in a bond can affect the extent to which the electrons are shared.

Polar Covalent Bonding
Type of covalent bonding where the atoms participating in a bond differ in electronegativity so the electrons in the bond are shared unequally.

Nonpolar Covalent Bonding
Type of covalent bonding where the atoms in a bond have the same electronegativity and share the electrons in the bond equally.

Homolytic Bond Cleavage
Process in which each atom involved in a bond obtains one electron forming radicals.

Heterolytic Bond Cleavage
Process in which one atom involved in bond obtains both electrons while the other atom gets no electrons. Ions are formed as a result.

Molecular Orbitals
Orbitals obtained by combining atomic orbitals in a molecule together.

Sigma Bonds
Bonds formed by the overlapping of orbitals in such a way that the electron density of the bond is located between the nuclei of the two atoms involved in the bond. Single bonds

obtained by one of three ways: two s orbitals overlapping, one s overlapping with an end of one p orbital, or two p orbitals overlapping end-on-end.

Pi Bonds
Bonds formed by the overlapping of orbitals in such a way that the electron density of the bond is located both above and below the plane of the nuclei involved in the bond. Pi bonds can be obtained by the side-to-side overlap of two p orbitals.

Hybrid Orbitals
The combination of two or more atomic orbitals to form a new orbital.

Resonance
A tool used in organic chemistry to describe molecules that can be drawn in more than one way.

Resonance Structure
Structures that can be drawn for a given molecule that differ only by the distribution of electrons. Each structure contributes to the overall picture of a molecule.

Resonance Hybrid
A composite of the various contributing resonance structures that gives a better description of a molecule than a single resonance structure could by itself.

Delocalized Electrons
Electrons that are not associated with just one atom or bond. Delocalized electrons are thought to lead to increased molecular stability.

Intermolecular Forces
Attractive forces between molecules.

London Dispersion Forces
Forces that occur between nonpolar molecules.

Dipole-Dipole Forces
Forces that occur between polar molecules.

Hydrogen Bonding
A type of dipole-dipole force that occurs between molecules with –OH, -NH, or HF.

03: IUPAC Rules: Organic Nomenclature I

Chapter Summary

Organic nomenclature, the rules for naming organic compounds, has two functions. First, the rules established in systems of nomenclature act to ensure that a person who hears or reads the name is under no ambiguity as to the compound to which it refers. One name can refer only to one chemical compound. Second, each name preferably conveys some information about the structure of a compound. In organic chemistry, the student is expected to be familiar with two systems of nomenclature: IUPAC nomenclature and common nomenclature. IUPAC nomenclature is a system of naming chemical compounds developed by the International Union of Pure and Applied Chemistry. It is a more formalized system than common nomenclature. IUPAC nomenclature uses a system of prefixes and suffixes to indicate the type of compound (what functional group is present in the molecule) present, the number of carbons in the longest, continuous chain in the molecule, and the type, number, and location of substituents on the parent chain. Common nomenclature uses prefixes to indicate the presence of certain common structural motifs in molecules. In order to fully understand the naming prefixes of common nomenclature, a discussion of the classification of carbons is also included.

Tutorial Features

- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts of nomenclature.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

IUPAC (International Union of Pure and Applied Chemistry) Nomenclature
  Parent chain
  Alkyl prefixes
  Substituents
  Numerical prefixes
  Halogen prefixes
  Rules used in naming compounds
Common Nomenclature
  Classification of carbons
  Rules used in naming compounds

Chapter Review

IUPAC Nomenclature

A system of naming chemical compounds developed by the International Union of Pure and Applied Chemistry. This system of nomenclature standardized the naming of compounds so that scientists around the world could communicate about molecules without confusion.

Parent Chain

The parent chain is the longest, continuous chain of carbons in a molecule.

Alkyl Prefixes

Prefixes that indicate the number of carbon atoms in the main chain. The table below lists the different alkyl prefixes:

Number of Carbons	Alkyl Prefix
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

Substituents

Any atom or group of atoms not part of the parent chain in a molecule.

Numerical Prefixes

Prefixes used to indicate when more than one of a particular substituent exists in a molecule. The table below lists the numerical prefixes used for naming identical groups:

Number of Identical Group Presen	Numerical Prefix
1	Mono-
2	Di-
3	Tri-
4	Tetra-
5	Penta-
6	Hexa-
7	Hepta-
8	Octa-
9	Nona-
10	Deca-

Halogen Prefixes

Prefixes used to indicate when a halogen (fluorine, chlorine, bromine, or iodide) is present as a substituent in a compound. The table below lists the halogen prefixes for each atom:

Halogen Atom	Halogen Prefix
Fluorine (F)	Fluoro-
Chlorine (Cl)	Chloro-
Bromine (Br)	Bromo-
Iodine (I)	Iodo-

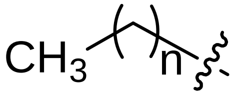
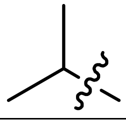
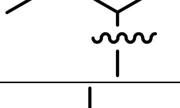
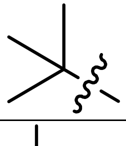
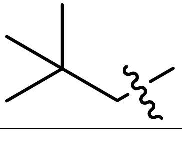
IUPAC Rules for Naming Compounds

There are two parts to every organic compound name in the IUPAC system: (1) the parent and (2) the substituents. The parent conveys the number of carbon atoms present in the longest chain through the use of an alkyl prefix and the functional group of the compound through the use of an appropriate suffix. The substituents are listed alphabetically before the parent in the name. Numerals are used to indicate their location on the main chain and numerical prefixes are used to indicate when more than one of a particular substituent exists. The following are rules used to name alkanes, alkenes, alkynes and alkyl halides:

1. Determine the longest, continuous chain of carbon atoms in the molecule. If the molecule contains an alkene or alkyne functional group, then the multiple bond(s) must be a part of the parent chain. Select the correct alkyl prefix that corresponds to the number of carbon atoms in the parent chain.
2. Determine the correct functional group suffix to use. Use the suffixes –ane for alkanes, -ene for alkenes, and –yne for alkynes. With alkyl halides, the molecules are named as alkanes with the halogens serving as substituents on the parent alkyl chain.
3. For alkanes, number the parent chain from the end that gives the lower number to the substituent encountered first.
4. For alkenes and alkynes, number the chain so that the multiple bonds have the lowest possible number. Place this location number in front of the parent name.
5. Naming substituents: For halogen substituents, use the halogen prefixes. For alkyl substituents, use the appropriate alkyl prefixes + -yl. Use numerical prefixes if more than one of a particular substituent exists in the molecule. Give the location of all substituents by placing the number of the carbon it is attached to in front of the substituent name.
6. Alphabetize the substituent groups, ignoring all numerical prefixes, in front of the parent name.
7. For alkenes, determine the relative configuration of the alkene if possible (cis versus trans). Place cis or trans in front of the substituent groups.

Common Nomenclature

Common nomenclature uses prefixes to indicate the presence of certain common structural motifs in molecules. The table below lists the different structural motifs in common nomenclature:

Name of Structural Motif	**Structure of Motif**
Straight Chain/Normal (n-)	
Iso-	
Secondary (sec-)	
Tertiary (tert-)	
Neo-	

The following are rules for naming alkyl halides using common nomenclature:

1. Name the compound as an alkyl halide. Use all of the carbons in the “alkyl” name.
2. Use the prefix “n” if the structure is a straight chain with the halogen on one end.
3. Use the prefix “iso” if the structure contains two methyl groups attached to a methine (CH) carbon.
4. Use the prefix “sec” if halogen is attached to the secondary carbon of a four carbon chain.
5. Use the prefix “tert” if the halogen is attached to the tertiary carbon of a group of four or five carbons.
6. Use the prefix “neo” if the halogen is attached to a carbon attached to four other carbons.

04: IUPAC Rules: Organic Nomenclature II

Chapter Summary

The theme of organic nomenclature is continued in this tutorial with the rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, amines and carboxylic acid derivatives being the focus of study. The IUPAC rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, amines and carboxylic acid derivatives build on those rules learned in the previous tutorial for alkanes, alkenes, alkynes, and alkyl halides. Also, the common nomenclature rules for naming alcohols, ethers, ketones, and amines will be examined.

Tutorial Features

- Examples and practice problems in the tutorial: Naming alcohols, ethers, aldehydes, ketones, amines and carboxylic acid derivatives.
- Visual representation of basic concepts of nomenclature.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

IUPAC Nomenclature
  Rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, and amines
  Rules for naming carboxylic acid derivatives
Common Nomenclature
  Rules for naming alcohols, ethers, ketones, and amines

Chapter Review

Functional Group Suffixes

The functional group suffix makes up part of the parent's name and communicates the functional group of the molecule immediately upon hearing/reading the compound's name. The table below lists the suffixes for the most commonly encountered functional groups in organic chemistry:

Functional Group	Suffix
Alkane	-ane
Alkene	-ene
Alkyne	-yne
Alkyl Halide*	-ane
Ether*	-ane
Alcohol	-anol
Aldehyde	-anal
Ketone	-anone
Carboxylic Acid	-anoic acid
Amine	-anamine

Ester	-anoate
Anhydride	Alkanoic alkanoic anhydride
Acid Halide	-anoyl halide
Amide	-anamide

Naming Alcohols, Ethers, Aldehydes, Ketones, Carboxylic Acids, and Amines

The rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, amines, and carboxylic acid derivatives in this tutorial build on those from the previous tutorial entitled "Organic Nomenclature I: How to Name Alkanes, Alkenes, Alkynes, and Alkyl Halides." The following are rules for naming alcohols, ethers, aldehydes, ketones, carboxylic acids, and amines:

1. Determine the appropriate alkyl prefix and functional group suffix for the parent chain in the molecule.
2. Number the chain so that the C-O or C-N bond has the lowest possible number. Indicate the position of the functional group using a number in front of the parent chain name.
3. For ethers, the compound is named as an alkane with the –OR group named as a substituent of the parent chain.
4. For amines, give the location of the attachment of the nitrogen to the parent amine and identify any groups attached to the nitrogen as substituents.
5. Give the location of each substituent with a number. Use numerical prefixes if more than one identical group is present.
6. Alphabetize the substituents, ignoring all numerical prefixes, in front of the parent chain's name.

Naming Carboxylic Acid Derivatives

In addition to the rules seen thus far for naming organic compounds, the following are IUPAC rules to be used in the naming of acid derivatives:

1. An ester is named by numbering the longest carbon chain beginning at the carbonyl carbon. List the alkyl group attached to the oxygen before any substituents.
2. An anhydride is named as an alkanoic alkanoic anhydride.
3. An acid halide is named as an alkanoyl halide.
4. An amide is named as an alkanamide. Any group attached to the nitrogen is numbered as "N".

Common Nomenclature

In addition to the common nomenclature rules seen thus far, the following are common nomenclature rules for naming alcohols, ethers, ketones, and amines:

1. Use common prefixes as needed.
2. An alcohol is named as an alkyl alcohol.
3. An ether is named as an alkyl alkyl ether. Alphabetize the two alkyl groups, ignoring any common prefixes like tert- or iso-.
4. A ketone is named as an alkyl alkyl ketone. . Alphabetize the two alkyl groups, ignoring any common prefixes like tert- or iso-.
5. For amines, the longest carbon chain attached to the nitrogen is the parent chain. List any additional substituents on the nitrogen in alphabetical order.

05: Drawing Organic Structures

Chapter Summary

Structures, not formulas, must be used in drawing organic structures. Double and triple bonds need to be shown in the structures. Structural formulas can be described as Lewis structures, condensed structures, skeletal structures, and sawhorse structures. Isomers can be classified as constitutional, configurational, or conformational. The common organic abbreviations are given in terms of names and structures.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Importance of Drawing Structures
  Structures, not Formulas
  Show Multiple Bonds
Types of Structures
  Lewis Structures
  Condensed Structures
  Skeletal Structures
  Sawhorse Structures
Isomers
  Constitutional Isomers
  Configurational Isomers
  Conformational Isomers
Abbreviations
  Names
  Structures

Chapter Review

Importance of drawing structures

A structure must be given, otherwise the product of the reaction cannot be determined. The location of single, double, and triple bonds must be specified.

Types of Structures

In Lewis structures, all individual bonds are shown. Formal charge is a way of keeping track of the electrons. Formal charge is equal to [number of valence electrons] B [nonbonding electrons] B 0.5 [bonding electrons]. In condensed structural formulas, atoms are bonded to a central atom are listed after the atom. In a skeletal structure, carbon atoms are assumed to be where two lines meet or at the end of the line. Hydrogens are not shown. In a sawhorse structure, the drawing is looking down the carbon-carbon bond.

Isomers

Constitutional isomers have the same formula, but different points of attachment. Configurational isomers have the same formula and the same point of attachment, but different orientation in space. Conformational isomers have the same formula and the same point of attachment, but the rotation about single bonds is different. In the eclipsed conformation of ethane, the front hydrogens block the back hydrogens. In the staggered conformation, the hydrogens are as far away from each other as possible. The staggered conformation is the most stable. For the conformations of butane, the front two carbons remain in place and the back two carbons rotate around the carbon 2 and carbon 3 bond. In the totally eclipsed conformation, one methyl blocks the other methyl. In the gauche conformation, the methyls are 60^o apart. In the eclipsed conformation, the methyls are 120^o apart. In the anti conformation, the methyls are 180^o apart. The stability of butane is anti > gauche > eclipsed > totally eclipsed.

Abbreviations

Me is an abbreviation for methyl, a CH_3-. Et is an abbreviation for ethyl, a CH_3CH_2-. Pr is an abbreviation for propyl, a $CH_3CH_2CH_2$-. Butyl is an abbreviation for butyl, a $CH_3CH_2CH_2CH_2$-. Ph is an abbreviation for phenyl, a benzene ring. Ar is an abbreviation for aromatic or aryl, a benzene ring. Ac is an abbreviation for acetyl, a methyl next to a C=O. Bz is an abbreviation for benzoyl, a benzene next to a C=O. Bn is an abbreviation for benzyl, a benzene attached to a CH_2. Pyr is an abbreviation for pyridine, a six-membered ring with alternating double and single bonds and containing nitrogen.

06: Functional Groups and Organic Compounds

Chapter Summary

Organic compounds can be categorized based on the functional groups they contain. Functional groups are specific, reactive groups of atoms that are responsible for the characteristics of the molecule that contains them. Molecules containing the same functional groups will undergo similar reactions. Also included in this tutorial is a section on acids and bases. Three different concepts of acidity and basicity are covered in this section: Arrhenius acid-base theory, Bronsted-Lowry acid-base theory, and Lewis acid-base theory. The different theories developed as our understanding of acids and bases grew. Finally, the tutorial looks at the basic rules for electron pushing in mechanisms.

Tutorial Features

- Concept map showing inter-connections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of concepts.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Organic Chemistry
    The chemistry of carbon
    Language of organic chemistry
Functional Groups
    Alkane, alkene, alkyne, aromatic
    Alkyl halide, alcohol, ether, thiol, sulfide
    Aldehyde, ketone, acid halide
    Carboxylic acid, ester, anhydride
    Amine, amide, nitrile
Acids and Bases
    Arrhenius
    Bronsted-Lowry
    Lewis
Electron Pushing
    Electrons and mechanisms
    Resonance and delocalization

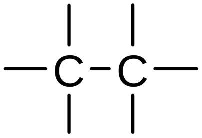
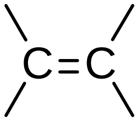
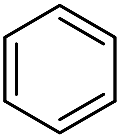
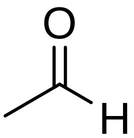
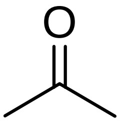
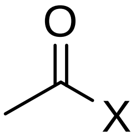
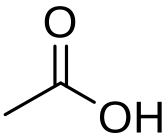
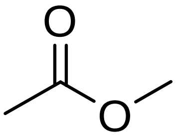
Chapter Review

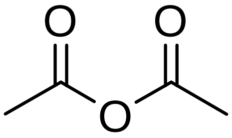
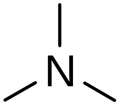
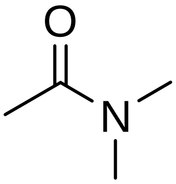
Organic Chemistry

The study of the chemistry of carbon compounds.

Functional Groups

Specific groups of atoms that impart characteristic reactivity to the molecules that contain them. The table below describes the structures of the most commonly encountered functional groups:

Functional Group	**Structure**
Alkane	
Alkene	
Alkyne	$-C\equiv C-$
Aromatic	
Alkyl Halide	$R-X$
Alcohol	$R-OH$
Ether	$R-O-R$
Thiol	$R-SH$
Sulfide	$R-S-R$
Aldehyde	
Ketone	
Acid Halide	
Carboxylic Acid	
Ester	

Anhydride	
Amine	
Amide	
Nitrile	$-C\equiv N$

Arrhenius Acid
A substance that dissociates to give the hydronium ion (H_3O^+).

Arrhenius Base
A substance that dissociates to give the hydroxide ion (^-OH).

Bronsted-Lowry Acid
A substance that can donate a proton (H^+).

Bronsted-Lowry Base
A substance that can accept a proton (H^+).

Conjugate Acid
A substance that results from the Bronsted-Lowry base gaining a proton (H^+).

Conjugate Base
A substance that results from the Bronsted-Lowry acid losing a proton (H^+).

Amphoteric Compound
A compound that can react as an acid or a base.

Lewis Acid
A substance that can accept electron pairs to form new bonds.

Lewis Base
A substance that can donate electron pairs to form new bonds.

Mechanism
A step by step explanation of what happens in a chemical reaction.

Nucleophile
The compound that donates the electrons in a mechanism (electron rich compound).

Electrophile
The compound that accepts the electrons in a mechanism (electron poor compound).

Delocalization

Electrons that are distributed among more than two atoms that are bonded together.

Electron Pushing

The process of moving electrons in a mechanism to illustrate what is occurring during a chemical reaction. Basic rules for drawing the movement of electrons in mechanisms have been established:

1. Identify the nucleophile. The nucleophile is typically the electron rich species and as such donates the electrons in a mechanism.
2. Identify the electrophile. The electrophile is typically the electron poor species and as such accepts the electrons in a mechanism.
3. The flow of electrons in a mechanism is **always** from the most electronegative atom to the least electronegative atom (or negative to positive).

07: Stereochemistry

Chapter Summary

Often times in chemistry, one runs across molecules that have the same molecular formula but possess a different structure. These molecules are called isomers. Isomers can be divided into three types: constitutional isomers, stereoisomers, and conformational isomers. The student must learn to distinguish between these three types of isomers. In this tutorial, the student will also be introduced to the concept of chirality and will learn how to find stereogenic centers in a molecule. This leads to a discussion of the different types of stereoisomers: enantiomers, diastereomers, and *cis/trans* (*E/Z)* isomers of alkenes. The student will learn how to distinguish enantiomers and diastereomers by assigning either an *R* or *S* configuration using the rules set forth in the *R/S* system. Finally, the tutorial will cover how to determine the relative and absolute configurations of alkenes including the rules for the *E/Z* system.

Tutorial Features

- Concept map showing inter-connections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts of stereochemistry.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Isomers
    Constitutional isomers
    Stereoisomers
    Conformational isomers
Basic Concepts of Stereochemistry
    Stereochemistry overview
    Chirality
    Stereoisomers
        Enantiomers
        Diastereomers
Assigning R and S Configurations to Chiral Centers
    Distinguishing enantiomers pairs by assigning their R and S configurations
    Assigning the absolute configuration to chiral compounds
    Meso compounds
Stereoisomers of Alkenes
    Relative configuration
    Absolute configuration

Chapter Review

Constitutional Isomers

Molecules with the same molecular formula, but different points of attachment.

Conformational Isomers

Molecules with the same molecular formula and points of attachment but differ by the rotation of a single bond.

Chirality

Chiral objects are not superimposable upon their mirror images while achiral objects can be superimposed upon their mirror images. Hands, ears, feet, and keys are examples of chiral objects. These objects do not contain planes of symmetry as symmetry is often an indicator of an object being achiral.

Chiral Carbon (Stereogenic Center, Stereocenter)

Carbon that has four different groups attached to it.

Stereoisomers

Molecules with the same molecular formula and points of attachment but different spatial orientation. There are three types of stereoisomers: enantiomers, diastereomers, and *cis/trans* (*E/Z*) isomers of alkenes. One can calculate the maximum number of stereoisomers that can exist for a chiral molecule by the solving the formula 2^n where n is the number of chiral centers present in the molecule.

Enantiomers

A molecule and its nonsuperimposable mirror image.

Assigning *R/S* Configurations to Chiral Centers

Chiral centers are assigned either *R* or *S* configurations based on the spatial arrangement of the groups on the stereogenic carbon. The method for assigning configurations involves determining the priority of the groups bound to the carbon.

1. Assign priority to the different groups on carbon with (1) being the highest priority group and (4) being the lowest priority group. The groups with the higher atomic mass/number will be given the higher priority. If the atomic mass/number of two groups is equal, then give the higher priority to the group that contains more branching.
2. Orient the molecule so that the lowest priority group is facing away from you.
3. Trace from priority group (1) through (2) to (3). If it is clockwise, assign the *R* configuration to the center. If it is counterclockwise, assign the *S* configuration to the center.

Diastereomers

Non-mirror image stereoisomers that contain more than one stereogenic center.

Meso Compounds

Molecules that contain more than one chiral center but that are achiral due to the presence of a plane of symmetry.

Relative Configuration of Alkenes

The relative configuration of an alkene is determined from the orientation of the parent chain through the double bond. An alkene is *trans* if the parent chain is on opposite sides of the double bond. An alkene is *cis* if the parent chain is on the same side of the double bond. The *cis/trans* system is typically used just for disubstituted alkenes as it becomes more difficult to assign a relative configuration to tri- and tetra-substituted alkenes.

Absolute Configuration of Alkenes

The absolute configuration of any alkene can be determined using the *E/Z* system. The *E/Z* system uses the priority rules used for assigning *R/S* to chiral centers. To assign the absolute configuration:

1. Divide the alkene at the double bond mentally or draw a line through the double bond to visually isolate the two ends of the double bond.
2. Assign priorities to each group attached to the double bond.
3. Compare the priorities. If the higher priority groups are coming off the same side of the double bond, then the configuration is *Z*. If the higher priority groups are coming off opposite sides of the double bond, then the configuration is *E*.

08: Conformational Analysis

Chapter Summary

Constitutional isomers, stereoisomers, and conformational isomers are defined. The conformations of ethane are staggered and eclipsed. The conformations of butane are anti, eclipsed methyl-hydrogen, gauche, and eclipsed. The bond angles of the cycloalkanes are given. Cyclohexane has the conformations of chair, boat, and twist-boat. The carbons in cyclohexane can be equatorial or axial.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Basic Concepts
    Constitutional Isomers
    Stereoisomers
    Conformational Isomers
Conformations of Ethane
    Staggered
    Eclipsed
Conformations of Butane
    Anti
    Eclipsed Methyl-Hydrogen
    Gauche
    Eclipsed
Bond Angles of Cycloalkanes
Conformations of Cyclohexane
    Chair
    Boat
    Twisted Boat

Chapter Review

Basic Concepts
Conformational analysis deals with the shapes that molecules can adopt by rotations about single bonds. These structures are called conformational isomers or conformers. The following isomers cannot interconvert between each other without breaking bonds. Constitutional isomers have the same formula, but different connectivity. Stereoisomers have the same formula, the same connectivity, but different arrangement in space. Conformational isomers are interconvertable isomers of the same molecule that result from

rotations of single bonds. They interconvert constantly and are not separable. Conformations of alkanes can best be viewed using either Newman projections or sawhorse representations. A Newman Projection is an end-on view of 2 carbons attached by a sigma bond. The front carbon is shown as the intersection of 3 bonds and the rear carbon is shown as a circle. The substituents are attached accordingly.

Conformations of Ethane

Ethane can adopt either staggered or eclipsed conformations. Staggered is the lowest energy conformer, with the hydrogens as far away from each other. Eclipsed is the highest energy conformer and the least stable. It is 3 kcal higher in energy than the staggered form due to repulsion between electrons in C-H bonds.

Conformations of Butane

As butane rotates about its sigma bond, four distinct conformational possibilities exist. Staggered, or anti, where the methyl groups are farthest apart; eclipsed methyl-H interactions; gauche, where the methyl groups are adjacent; and eclipsed, or syn, where the methyl groups are eclipsed.

Cycloalkanes

The interior angles of cycloalkanes deviate from the tetrahedral so strain develops. Cyclopropane has a bond angle of 60^o; Cyclobutane has a bond angle of 90^o; Cyclopentane has a bond angle of 108^o; Cyclohexane has a bond angle of 109.5^o.

Conformations of Cyclohexane

Cyclohexane=s Newman Projection illustrates the staggered, low energy conformation that the chair form results. In addition to the chair, cyclohexane can also adopt the boat form by flipping one hydrogen up. This form is higher in energy due to steric and eclipsing strain. By twisting the boat, cyclohexane adopts yet another form, the twist-boat, a result of relieving some of the boat=s strain. Cyclohexane=s carbons have two substitution positions, axial and equatorial. The axial is vertical and equatorial is parallel to the adjacent C-C bond in the chair.

09: Saturated Hydrocarbons

Chapter Summary

Now that the student has learned the basics of organic chemistry in the first six tutorials, the student will begin learning about the more specific aspects of each functional group—their properties, uses and reactions. In this, the seventh tutorial, the physical properties, uses, structures, nomenclature, and reactions of alkanes, cycloalkanes, and alkyl halides are examined.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Definitions
    Hydrocarbons
    Alkanes
    Cycloalkanes
    Alkyl halides
Properties and Uses of Alkanes and Cycloalkanes
    Properties
    Structure and conformations
    Uses
Properties and Uses of Alkyl Halides
    Properties
    Uses
Alkane and Cycloalkane Nomenclature
    IUPAC nomenclature
    Common nomenclature
Nomenclature of Alkyl Halides
    IUPAC nomenclature
    Common nomenclature
Reactions of Alkanes
    Combustion
    Cracking
    Halogenation

Chapter Review

Hydrocarbons
Organic compounds that contain only carbons and hydrogens.

Alkanes
Non-cyclic hydrocarbons; simplest functional group.

Cycloalkanes
Cyclic hydrocarbons.

Alkyl Halides
Alkanes or cycloalkanes that contain a halogen atom(s).

Hydrophobic
Literally 'water hating". Often used to described molecules or parts of molecules that will not dissolve in water.

Eclipsed Conformation
Describes a molecular conformation where the atoms attached to one carbon line up with the atoms attached to an adjacent carbon (*i.e.* the dihedral angle is 0 degrees.).

Staggered Conformation
Describes a molecular conformation where the atoms attached to one carbon are as far away from the atoms attached to an adjacent carbon atom. Staggered conformations are more stable than eclipsed conformations.

Gauche Conformation
Describes a molecular conformation where two observed atoms on adjacent carbons are 60 degrees apart.

Anti Conformation
Describes a molecular conformation where two observed atoms on adjacent carbons are 180 degrees apart.

Chair Conformation
Describes a molecular conformation of cyclohexane where the hydrogens on the ring are the furthest apart. This is the most stable conformer of cyclohexane.

Boat Conformation
Describes a molecular conformation of cyclohexane where the hydrogens are very close to each other. This is the least stable conformer of cyclohexane.

Alkane and Cycloalkane Nomenclature
The student is reintroduced to alkane nomenclature, both IUPAC and common, in this tutorial. In addition, new rules for cycloalkanes are covered. The following are the IUPAC rules for naming cycloalkanes:

1. Number the cycloalkane so that the lowest possible combination of numbers are used for the substituents.

2. If the compound contains an aliphatic ring and a chain, the parent compound is the one with the most carbons.

The common rules for naming cycloalkanes:

1. Use the common prefixes as needed.
2. List substituents alphabetically in front of the cycloalkane name.

Key Reactions of Alkanes:

1) Combustion of Alkanes
Converts alkanes to carbon dioxide and water. To determine what the balanced reaction equation would be for any alkane, one can use the following formula where n is the number of carbons in the alkane:

$$C_nH_{(2n+2)} + \left(\frac{3n+1}{2}\right)O_2 \longrightarrow nCO_2 + (n+1)H_2O$$

2) Cracking of Alkanes
Cracking of hydrocarbons at high temperatures (usually a catalyst is also required) yields a mixture of smaller alkanes and alkenes.

3) Halogenation of Alkanes
Alkanes can be halogenated in the presences of heat or light and X_2, where X is a halogen. Halogenation of alkanes occurs through a radical mechanism that can be divided into three different types of steps: initiation, propagation, and termination.

Initiation Step
The first step of a radical halogenation reaction of an alkane. In this step, the initial halogen radicals are formed by the interaction of a diatomic halogen with light or heat.

Propagation Step
The second part of a radical halogenation reaction of an alkane where radicals are both consumed and formed. In these steps, the initial halogen radical attacks an alkane and abstracts a hydrogen from it to form an alkyl radical and a molecule of HX. Next, the alkyl radical attacks a molecule of X_2 to form a haloalkane and a halogen radical. One should always (1) have a radical on either side of the arrow in propagation steps and (2) reform the initial halogen radical at the end of the second propagation step.

Termination Step
The last step of a radical halogenation reaction where radicals are consumed. Two radicals will react to form a neutral, stable organic compound.

10: Unsaturated Hydrocarbons

Chapter Summary

Background information for alkenes, alkynes, and dienes are described in terms of definitions, properties, uses, structures, and classification. The rules for the IUPAC nomenclature of alkenes, alkynes, and dienes are discussed. Alkenes are additionally named using cis and trans or E and Z. Alkenes are synthesized by the dehalogenation of alkyl halides and the dehydration of alcohols. Alkynes are synthesized by the dehydrohalogenation of vicinal and geminal dihalides. Alkyl halides are formed by the reaction of alkenes with hydrogen halides. Alkenes are halogenated to give dihaloalkanes. Alkenes are hydrated to give alcohols. Reduction of alkenes give alkanes. Alkynes react with hydrogen halides to give dihaloalkanes or with halogens to give tetrahaloalkanes. Hydrogenation of alkynes give alkanes. Alkenes are polymerized. Alkenes are oxidized to diols with potassium permanganate or to aldehydes and / or ketones with ozone. Alkynes are oxidized to diketones with potassium permanganate or to carboxylic acids with ozone.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

- Background Information for Alkenes, Alkynes, and Dienes
  - Definitions
  - Properties
  - Uses
  - Structure
  - Classification
- Nomenclature of Alkenes, Alkynes, and Dienes
  - IUPAC
  - Cis and Trans
  - E and Z
- Synthesis of Alkenes
  - Dehalogenation of Alkyl Halides
  - Dehydration of Alcohols
  - Products of Elimination Reactions
- Synthesis of Alkynes
  - Dehydrohalogenation of Vicinal Dihalides
  - Dehydrohalogenation of Geminal Dihalides
- Reactions of Alkenes
  - Definitions
  - Addition of Hydrogen Halides

  - Halogenation
  - Hydration
  - Hydrogenation
- Reactions of Alkynes
  - Addition of Hydrogen Halides
  - Halogenation
  - Hydrogenation
- Polymerization of Alkenes
  - Definitions
  - Examples
- Oxidation of Alkenes and Alkynes
  - Potassium Permanganate Oxidation
  - Ozonolysis

Chapter Review

Background for Alkenes, Alkynes, and Dienes

Alkenes contain carbon-carbon double bonds. Alkynes contain carbon-carbon triple bonds. Dienes contain more than one carbon-carbon double bond. Alkenes, alkynes, and dienes are less dense than water, are nonpolar, and have boiling points and melting points similar to alkanes. The carbon in an alkene is sp^2, has a bond angle of 120^o, and a trigonal planar shape. A carbon-carbon double bond contains one sigma bond and one pi bond. No rotation is possible around a carbon-carbon double bond. The carbon in an alkyne is sp, has a bond angle of 180^o, and a linear shape. A carbon-carbon triple bond contains one sigma bond and two pi bonds. In dienes, allenes contains two double bonds that share a carbon. Conjugated dienes have double bonds that alternate with single bonds. Isolated dienes have double bonds that are separated by two or more single bonds. In an unsubstituted alkene, no alkyl groups are attached to a carbon-carbon double bond. In a monosubstituted alkene, one R group is attached to the carbon-carbon double bond. In a disubstituted alkene, two alkyl groups are attached to the carbon-carbon double bond. In a trisubstituted alkene, three alkyl groups are attached to the carbon-carbon double bond. In a tetrasubstituted alkene, four alkyl groups are attached to the carbon-carbon double bond. A terminal alkyne contains at least one hydrogen attached to the carbon-carbon triple bond. An alkyne that is not terminal contains two alkyl groups attached to the carbon-carbon triple bond.

Nomenclature of Alkenes, Alkynes, and Dienes

Circle the longest continuous carbon chain as the parent compound. Use Aene@ for alkene, and Ayne@ for alkyne. Number from whichever end that gives the lowest possible number for the multiple bonds. Name and number substituents. If both a double bond and a triple bond are present, number from whichever end that gives the lowest possible number for the multiple bonds. If the double bond and a triple bond are equal distance, then the double bond has priority over the triple bond. Name compounds with a double bond and a triple bond as enyne, giving positions of the multiple bonds. OH has priority over double and triple bonds. Cis has the same group on the same side. Trans has the same group on opposite sides. In the Cahn-Ingold-Prelog rules, Z has the highest ranking group on the same side and E has the highest ranking group on opposite sides. Rank the first atoms directly attached to the carbon-carbon double bond. The atom with the highest atomic number has the highest ranking. If the priority cannot be determined by Rule 1, then compare the next group of atoms. Double bonds are duplicated and triple bonds are triplicated, with imaginary atoms.

Synthesis of Alkenes

Alkyl halides are dehydrohalogenated with base to form alkenes. Alcohols are dehydrated with heat and acid to form alkenes. The product with the most number of carbons attached to the carbon-carbon double bond is formed in the higher yield.

Synthesis of Alkynes

Vicinal dihalides are dehydrohalogenated twice with base to form alkynes. Geminal dihalides are dehydrohalogenated twice with base to form alkynes.

Reactions of Alkenes

In Markovnikov addition, H of HZ adds to carbon with most hydrogens directly attached; the more stable carbocation intermediate is formed. In anti addition, the groups add on opposite sides of the double bond. In syn addition, the groups add on the same side of the double bond. A regioselective reaction is a reaction in which one of two possible isomers predominates. A regiospecific reaction is a reaction in which one of two possible isomers is formed exclusively. An hydrogen halide adds across a double bond to form an alkyl halide, via Markovnikov addition. Halogen adds across a double bond to form a dihalolalkane, with anti addition. Water adds across a double bond to produce an alcohol, via Markovnikov addition. Hydrogen adds across a double bond, via syn addition, to form an alkane.

Reactions of Alkynes

Hydrogen halide adds across a triple bond, via Markovnikov addition and with anti or syn addition, to form dihaloalkanes. Halogen adds across a triple bond to form a tetrahaloalkane. Hydrogen adds across a triple bond to make an alkane.

Polymers of Alkenes

Ethylene is polymerized to polyethylene, which is used for bags, films, and bottles. Propylene is polymerized to polypropylene, which is used for plastics. Styrene is polymerized to polystyrene, which is used for plastics, plastic cups, and foam insulation. Methyl α-methacrylate is polymerized to polymethyl α-methacrylate, which is used for plexiglass and Lucite paints. Acrylonitrile is polymerized to polyacrylonitrile, which is used as Orlon or Acrylan fibers. Tetrafluoroethylene is polymerized to polytetrafluoroethylene, which is used as Teflon. Vinyl chloride is polymerized to polyvinyl chloride, which is used in plastics, films, and plumbing. Vinylidene chloride is polymerized to polyvinylidene chloride, which is used in Saran.

Oxidation Reactions of Alkenes and Alkynes

Potassium permanganate oxidizes alkenes to diols, with syn addition. Ozone oxidizes alkenes to aldehydes and / or ketones. Potassium permanganate oxidizes alkenes to diketones. Ozone oxidizes alkynes to carboxylic acids.

11: Aromatic Compounds and Aromaticity

Chapter Summary

Kekule proposed the structure of benzene in 1865. The carbons in benzene are sp^2 hybridized, have a bond angle of 120°, and have a trigonal planar shape. The equation for Huckel=s rule is given. The criteria for aromatic, antiaromatic, and not aromatic are described. The special names for the monosubstituted benzenes are listed. The rules for the nomenclature of aromatic compounds are described. Ortho, meta, and para definitions are given. The structures of anthracene, naphthalene, and phenanthrene are drawn out. The mechanism for electrophilic aromatic substitution is discussed, along with specific examples of other examples. Halogenation of benzene produces halobenzene. Nitration of benzene gives nitrobenzene. Sulfonation of benzene yields benzenesulfonic acid. The Friedel-Craft alkylation of benzene gives alkylbenzene. The Friedel-Craft acylation of benzene produces a ketone.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Aromatic Compounds
    History Lesson
    Structure of Benzene
    Drawing Benzene
    Determining Aromaticity
Nomenclature of Aromatic Compounds
    Special Names
    IUPAC Nomenclature
    Disubstituted Benzene Derivatives
    Aromatic Fused Rings
Reactions of Aromatic Compounds
    Electrophilic Aromatic Substitution
    Halogenation
    Nitration
    Sulfonation
    Friedel-Craft Alkylation
    Friedel-Craft Acylation

Chapter Review

Background for Aromatic Compounds

Kekule proposed the structure of benzene in 1865. The carbons in benzene are sp^2 hybridized, have a bond angle of 120^o, and have a trigonal planar shape. Benzene can be drawn with all carbons and hydrogens, with just lines, or using a circle in the ring.

Aromaticity, Huckel=s rule

Pi electrons are counted as follows: each double bond counts as two pi electrons, each + charge counts as zero pi electrons, each B charge counts as two pi electrons, each radical counts as one pi electron. Set the total number of pi electrons as equal to 4n + 2; solve for n. If the compound is aromatic, then it is cyclic with a continuous ring of overlapping p orbitals and n equals a whole number. If the compound is antiaromatic, then it is cyclic with a continuous ring of overlapping p orbitals, but n does not equal a whole number. If the compound is not aromatic, then it is noncyclic or is cyclic without a continuous ring of overlapping p orbitals.

Nomenclature of Aromatic Compounds

$C_6H_5CH_3$ is named toluene. C_6H_5OH is named phenol. $C_6H_5NH_2$ is named aniline. $C_6H_5OCH_3$ is named anisole. $C_6H_5CH=CH_2$ is named styrene. A benzene with an aldehyde group is named benzaldehyde. A benzene with a methyl ketone group is called acetophenone. A benzene with a carboxylic acid group is named benzoic acid. The benzene is the parent compound. Number the ring so that the groups have the lowest possible numbers. If a special name is used for a benzene derivative, then that group is in position one; then number the other groups. Ortho means that the two groups are on adjacent carbons or on the 1,2 positions. Meta means that the two groups are separated by one carbon or on the 1,3-positions. Para means that the two groups are on opposite ends or on the 1,4-positions. The fused ring structures of anthracene, naphthalene, and phenanthrene are drawn out.

Reactions of Aromatic Compounds

Benzene is halogenated with bromine and iron (III) bromide; chlorine and aluminum chloride; or iodine and nitric acid to give a halobenzene. Nitration of benzene with nitric acid, in the presence of sulfuric acid, produces nitrobenzene. Benzene is sulfonated with sulfur trioxide, in the presence of sulfuric acid, to yield benzenesulfonic acid. In Friedel-Craft alkylation, benzene reacts with aluminum chloride and alkyl halide to form an alkylbenzene. In Friedel-Craft acylation, benzene reacts with aluminum chloride and an acid halide to form a ketone.

12: Alcohols and Ethers

Chapter Summary

Alcohols and ethers are both oxygen containing functional groups. In this tutorial, the student will learn about the structures and properties of each functional group. The IUPAC nomenclature of alcohols and ethers will also be re-introduced. The different reactions used to synthesis alcohols and ethers will be covered as will the reactions each functional group undergoes.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Alcohols and Ethers
    Definitions
    Properties
    Uses
    Classification of alcohols
Nomenclature for Alcohols and Ethers
    IUPAC nomenclature
    Common nomenclature
Physical Properties of Alcohols
    Hydrogen bonding
    Boiling points of alcohols
    Water solubility of alcohols
    Acidity of alcohols
Synthesis of Alcohols
    From alkenes
    From alkyl halides
    From organometallic reagents reacting with aldehydes and ketones
    From reduction of aldehydes and ketones
Reactions of Alcohols
    Formation of alkoxide ions
    Formation of alkyl halides
    Dehydration
    Oxidation
    Esterification
    Pinacol rearrangement
    Preparation of leaving groups

Synthesis and Reactions of Ethers
    Williamson ether synthesis
    Cleavage of ethers

Chapter Review

0^0 Alcohol
Alcohol with no alkyl groups attached to the carbon bearing the hydroxyl group.

Primary Alcohol
Alcohol with one alkyl group attached to the carbon bearing the hydroxyl group.

Secondary Alcohol
Alcohol with two alkyl groups attached to the carbon bearing the hydroxyl group.

Tertiary Alcohol
Alcohol with three alkyl groups attached to the carbon bearing the hydroxyl group.

Phenol
Alcohol where the hydroxyl group is attached to a benzene ring.

Nomenclature for Alcohols and Ethers
The student is re-introduced to the IUPAC and common nomenclature rules used to name alcohols and ethers. Remember that ethers are named as an alkane with the –OR group given as a substituent.

Reactions Used to Synthesis Alcohols:

1) Hydration of Alkenes
Alkenes react with water in the presence of acid to form alcohols.

2) Formation from Alkyl Halides
Alkyl halides react with a source of hydroxide to produce alcohols.

3) Reaction of Organometallic Reagents with Aldehydes and Ketones
Aldehydes and ketones react with organolithium reagents or Grignard reagents followed by treatment with an aqueous acid to produce alcohols.

4) Reduction of Aldehydes and Ketones
Aldehydes and ketones may be reduced to alcohols using several different reducing agents: hydrogen gas and Raney nickel, lithium aluminum hydride, or sodium borohydride.

Reactions of Alcohols:

1) Formation of Alkoxide Ions
Alcohols are deprotonated with sodium or potassium metal to form an alkoxide ion. Hydrogen gas is a by product.

2) Formation of Alkyl Halides

(1) Alcohols react with hydrogen halides to displace the hydroxyl group and form alkyl halides. (2) Alcohols can react with phosphorus trihalides to produce alkyl halides. (3) Alcohols can react with thionyl chloride to produce alkyl chlorides.

3) Dehydration

Alcohols, when treated with acid and heat, will undergo elimination of the hydroxyl group to form alkenes.

4) Oxidation of Alcohols

(1) Primary alcohols are oxidized with PCC (pyridinium chlorochromate) to form aldehydes. (2) Primary alcohols are oxidized to carboxylic acids using several different oxidants: potassium permanganate, sodium hypochlorite, nitric acid, chromium trioxide, etc. (3) Secondary alcohols are oxidized to ketones using several different oxidants: potassium permanganate, sodium hypochlorite, nitric acid, chromium trioxide, PCC, etc.

Remember, tertiary alcohols can not be oxidized.

5) Esterification

Alcohols react with carboxylic acids in the presence of acid to form esters.

6) Pinacol Rearrangement

A reaction in which a diol is dehydrated to form a rearranged ketone product.

7) Preparation of Leaving Groups

Alcohols can be converted into better leaving groups by reacting them with sulfonyl chlorides to form alkyl sulfonates.

Synthesis and Reactions of Ethers:

1) Williamson Ether Synthesis

Alkoxide ions will react with alkyl halides to form ethers.

2) Cleavage of Ethers

Ethers can be cleaved using hydrogen halides to form alkyl halides and alcohols. The alkyl group that comprises the alkyl halide is usually the least hindered alkyl group from the ether.

13: Aldehydes and Ketones

Chapter Summary

Aldehydes and ketones are carbonyl containing functional groups with very interesting and useful chemistries. In this tutorial, the student will learn about the structure of these compounds, their keto-enol tautomerism, and the reactions they undergo. Additionally, the nomenclature rules for these groups will be reviewed. New functional groups will also be introduced and are summarized in a table at the end of this summary.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Aldehydes and Ketones
    Structure
    Shape
    Properties
    α-Hydrogens
    Keto-enol tautomerism
Nomenclature for Aldehydes and Ketones
    IUPAC nomenclature
    Common nomenclature
Synthesis of Aldehydes and Ketones
    Oxidation of alcohols
    Friedel-Crafts acylation of benzene
    Ozonolysis of alkenes
    From acid halides
Reactions of Aldehydes and Ketones
    Reactions with organometallic reagents
    Reduction to alcohols
    Reduction to alkanes
    Formation of imine derivatives
    Oxidation
    Acetal formation
    Reactions at the α-carbon
        Acetoacetic ester synthesis
        Aldol condensation
        Haloform reaction

Chapter Review

α-Carbon
A carbon atom next to a carbonyl.

α-Hydrogen
A hydrogen on an α-carbon. These hydrogens are somewhat acidic due to the negative charge on the resulting enolate being delocalized by resonance.

Keto-Enol Tautomerism
Process by which an aldehyde or ketone and its enol equilibrate.

Nomenclature of Aldehydes and Ketones
The student is re-introduced to the IUPAC and common nomenclature rules applied to aldehydes and ketones that were originally covered in tutorial 6.

Synthesis of Aldehydes and Ketones:

1) Oxidation of Alcohols
(1) Primary alcohols are oxidized with PCC (pyridinium chlorochromate) to form aldehydes. (2) Secondary alcohols can be oxidized with several different oxidants: potassium permanganate, sodium hypochlorite, nitric acid, PCC, chromium trioxide, etc.

2) Friedel-Crafts Acylation of Benzene
Benzene will react with acid halides in the presence of aluminum trichloride to produce ketones.

3) Ozonolysis of Alkenes
Alkenes are oxidized to aldehydes/ketones with ozone (O_3). Whether one obtains aldehydes, ketones, or a mix of both depends on the substitution pattern of the alkene.

4) Conversion from Acid Chlorides
(1) Acid halides can be reduced with tri-tert-butyl lithium aluminum hydride to form aldehydes. (2) Acid chlorides react with dialkyl copper lithium reagents to form ketones.

Reactions of Aldehydes and Ketones:

1) Reaction with Organometallics
Aldehydes and ketones react with organolithium or Grignard reagents, followed by acidification, to produce alcohols.

2) Reduction to Alcohols
Several different reducing agents can reduce aldehydes and ketones to alcohols: hydrogen and Raney nickel, lithium aluminum hydride, or sodium borohydride.

3) Reduction to Alkanes
(1) Aldehydes and ketones are reduced to alkanes with zinc-mercury amalgam (Zn(Hg))and hydrochloric acid. This is called the **Clemmenson reduction**. (2) Aldehydes and ketones are reduced to alkanes with hydrazine (NH_2NH_2) and potassium hydroxide. This is called the **Wolff-Kishner reduction**.

4) Formation of Imine Derivatives

(1) Aldehydes and ketones react with ammonia, primary amines, and their derivatives in the presence of an acid catalyst to form imine derivatives.

5) Formation of Enamines

Secondary amines will react with aldehydes or ketones to form enamines. The β-carbon of an enamine is nucleophile and can react readily with primary and secondary alkyl halides and acid halides.

6) Oxidation to Carboxylic Acids

Aldehydes can be oxidized to carboxylic acids using several different oxidants: potassium permanganate, nitric acid, chromium trioxide, sodium hypochlorite, etc.

7) Acetal Formation

Aldehydes and ketones react with alcohols to form hemiacetals and acetals.

Reactions at the α-Carbon of Ketones and Aldehydes:

1) Reactions of Enamines

Enamines, formed by the reaction of aldehydes or ketones with secondary amines, can act as nucleophiles and attack different electrophiles like alkyl halides and acid halides.

2) Oxidative Cleavage of Cyclic Ketones

Cyclic ketones can undergo oxidative cleavage at the α-carbon via reaction with their enol forms.

3) Acetoacetic Ester Synthesis

β-Keto esters contain acidic α-hydrogens that can be deprotonated to form an enolate anion. The enolate, which is nucleophilic, can then be used to attack electrophiles. This type of reaction would form a new bond between the α-carbon and the electrophile. In addition, the ester may be hydrolyzed to the β-keto acid and then decarboxylated to form a ketone product.

4) Aldol Condensation

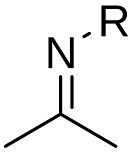
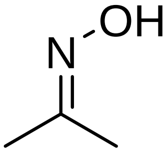
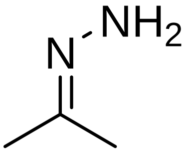
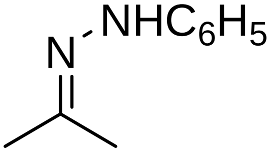
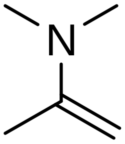
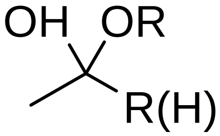
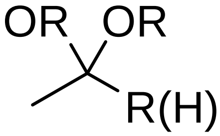
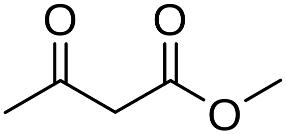
Condensation of two aldehydes or ketones that can be either base- or acid-catalyzed. The initial product of the aldol condensation is a β–hydroxyketone. The β–hydroxyketone will dehydrate in the presence of heat and an acid catalyst to form a α, β-unsaturated ketone.

5) Haloform Reaction

A base catalyzed (usually a hydroxide base) halogenation of methyl ketones that proceeds via an enolate anion. If an excess of base is present, the trihalomethyl ketone, the initial product, will then undergo nucleophilic attack from the hydroxide ion to yield a haloform (CHX_3) and a carboxylic acid.

New Functional Groups Introduced in this Tutorial:

Functional Group	Structure of Group

Imine	
Oxime	
Hydrazone	
Phenylhydrazone	
Enamine	
Hemiacetal	
Acetal	
β-Ketoesters	

14: Carboxylic Acids

Chapter Summary

Carboxylic acids act not only as a functional group but also as the source for several other functional groups known collectively as acid derivatives. In this tutorial, the student will learn about the structure, acidity and other properties of carboxylic acids. The IUPAC nomenclature rules for naming acids are re-introduced. Finally, the different reactions used to synthesize acids and the reactions acids undergo will be examined.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Carboxylic Acids
    Structure
    Shape
    Physical properties
Acidity
    Acidity of carboxylic acids
    Resonance stability of the carboxylate anion
    Inductive effects on acidity
Nomenclature of Carboxylic Acids
    IUPAC nomenclature
    Common nomenclature
Synthesis of Carboxylic Acids
    Oxidation of primary alcohols
    Oxidation of aldehydes
    Carboxylation of Grignard reagents
    Hydrolysis of nitriles
Reactions of Carboxylic Acids
    Reduction to primary alcohols
    Conversion to acid halides
    Esterification
    Conversion to anhydrides
    Decarboxylation

Chapter Review

Carboxylate Anion

The anion formed with the acidic proton of a carboxylic acid is deprotonated. This anion is resonance stabilized.

IUPAC Nomenclature Rules for Carboxylic Acids

The rules for naming carboxylic acids, previously introduced in tutorial 6, are examined again.

Reactions Used to Synthesize Carboxylic Acids:

1) Oxidation of Primary Alcohols

Primary alcohols may be oxidized to the carboxylic acid using a number of different oxidants: nitric acid, sodium hypochlorite, potassium permanganate, chromium trioxide, etc.

2) Oxidation of Aldehydes

Aldehydes may be oxidized to the carboxylic acids using a number of different oxidants: nitric acid, sodium hypochlorite, chromium trichloride, etc.

3) Carboxylation of Grignard Reagents

Reaction of Grignard reagents with carbon dioxide followed by treatment with aqueous acid forms carboxylic acids.

4) Hydrolysis of Nitriles

Nitriles may be hydrolyzed with aqueous acid to form carboxylic acids.

Reactions of Carboxylic Acids:

1) Reduction to Alcohols

Acids may be reduced to primary alcohols using lithium aluminum hydride followed by treatment with aqueous acid.

2) Conversion to Acid Halides

Carboxylic acids react with thionyl chloride to form acid chlorides.

3) Esterification

Reaction of carboxylic acids with alcohols in the presence of acid forms esters.

4) Conversion to Anhydrides

Reaction of carboxylic acids with acid chlorides to form anhydrides.

5) Decarboxylation

When heated, carboxylic acids can undergo loss of carbon dioxide.

15: Acid Derivatives

Chapter Summary

Acid derivatives are different functional groups that can all be synthesized directly from carboxylic acids. The different acid derivatives (acid halides, anhydrides, esters, amides) are introduced in this tutorial. The student will learn about their structure, relative reactivity, nomenclature, and reactions.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

- Background Information for Acid Derivatives
  - Structure
  - Shape
  - Properties
  - Relative reactivity of acid derivatives
- Nomenclature of Acid Derivatives
  - Rules for acid halides
  - Rules for esters
  - Rules for anhydrides
  - Rules for amides
- Reactions of Acid Halides
  - Hydrolysis
  - Conversion to esters
  - Conversion to amides
  - Reduction to alcohols
  - Reduction to aldehydes
  - Conversion to ketones
- Reactions of Esters
  - Hydrolysis
  - Saponification
  - Transesterification
  - Reduction to alcohols
  - Conversion to amides
- Reactions of Anhydrides
  - Hydrolysis
  - Conversion to esters

  - Conversion to amides
- Reactions of Amides
  - Hydrolysis
  - Hofmann Rearrangement
  - Reduction to amines
  - Dehydration

Chapter Review

Acid Derivatives
Functional groups that can be made directly from carboxylic acids.

IUPAC Nomenclature Rules for Naming Acid Derivatives
The student is re-introduced to the IUPAC nomenclature rules for naming acid derivatives that were originally covered in tutorial 6.

Reactions of Acid Halides

1) Hydrolysis
Acid halides are hydrolyzed to carboxylic acids using water.

2) Conversion to Esters
Acid halides will react with alcohols to form esters.

3) Conversion to Amides
Amines will react with acid halides to form amides.

4) Reduction to Alcohols
Acid halides can be reduced to form alcohols using lithium aluminum hydride.

5) Reduction to Aldehydes
Using tri-tert-butyl lithium aluminum hydride, acid halides can be reduced to form aldehydes.

6) Conversion to Ketones
Acid halides can be converted to ketones by using dialkyl copper lithium reagents.

Reactions of Esters:

1) Hydrolysis
Esters are hydrolyzed to carboxylic acids and alcohols using aqueous acid.

2) Saponification
Base catalyzed hydrolysis of esters using a strong base to form the salt of a carboxylic acid and an alcohol.

3) Transesterification
Reaction of an ester with an alcohol in the presence of an acid catalyst to form a new ester.

4) Reduction to Alcohols
Esters react with lithium aluminum hydride to produce alcohols.

5) Conversion to Amides
Esters react with amines to yield amides and alcohols.

Reactions of Anhydrides:

1) Hydrolysis
Anhydrides can be hydrolyzed with water to form carboxylic acids.

2) Conversion to Esters
Anhydrides react with alcohols to produce esters and carboxylic acids.

3) Conversion to Amides
Anhydrides can be converted to amides and carboxylic acids using amines.

Reactions of Amides:

1) Hydrolysis
(1) Amides are hydrolyzed with aqueous acid to form carboxylic acids and ammonium ions.
(2) Amides can be hydrolyzed with base to form anions of carboxylic acids and amines.

2) Hofmann Rearrangement
Reaction in which amides are converted to a primary amine with one less carbon than the starting amide. The reaction is catalyzed by a strong base and diatomic bromine.

3) Reduction
Amides are reduced in the presence of lithium aluminum hydride to form amines.

4) Dehydration
Primary amides can be dehydrated with $POCl_3$ or P_2O_5 to form nitriles.

16: Keto Acids and Esters

Chapter Summary

Keto acids and esters offer a large range of synthetic possibilities to a chemist. In this tutorial, the student will learn about their structure, their nomenclature, and the reactions they undergo. The student will also examine their keto-enol tautomerism and will learn how their tautomerism differs from that of a compound containing a single carbonyl functionality.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Keto Acids and Esters
    Definitions
    Nomenclature
    Acidity of the α-hydrogen
    Keto-enol tautomerism
Reactions of Keto Acids and Esters
    Decarboxylation
    Acetoacetic acid synthesis

Chapter Review

β-Keto Acid
Carboxylic acids with a carbonyl group two carbons away at the β position (carbon-3).

β-Keto Ester
Esters with a carbonyl group two carbons away at the β position (carbon-3).

Nomenclature of Keto Acids and Esters
The IUPAC nomenclature rules for naming keto acids and esters are covered in this tutorial:

1. Keto acids are named as carboxylic acids. The ketone group is listed as a substituent using the prefix "oxo-".
2. Keto esters are named as esters. The ketone group is listed as a substituent using the prefix "oxo-".

α-Hydrogen
A hydrogen on the carbon between the carbonyls of a keto acid or ester. This type of hydrogen is acidic due to the resonance stabilization of the enolate resulting from deprotonation.

Keto-Enol Tautomerism
If at least one α-hydrogen is present on the α-carbon of a keto acid or ester, then the compounds will exist in equilibrium with their enol forms.

Decarboxylation of β-Keto Acids
A type of reaction that β-keto acids undergo, but not β-keto esters, where the carboxylic acid group of the molecule, when heated, is lost as a molecule of carbon dioxide. A ketone is the final product of this reaction.

Acetoacetic Synthesis
Previously covered in tutorial 10, "Aldehydes and Ketones," this reaction involved deprotonating the α-carbon of a β-keto ester to form an enolate. The enolate anion acts as a nucleophile and attacks an electrophile forming a new carbon-carbon bond to the α-carbon. One may isolate the alkylated β-keto ester or the ester product can then be hydrolyzed to form a carboxylic acid and then decarboxylated to form a ketone.

17: Amines

Chapter Summary

Amines are one of the few functional groups that can act both as a nucleophile and base. In this tutorial, the student will learn about the structure of amines, their physical properties, and their basicity. In addition, the IUPAC and common nomenclature rules for naming amines are revisited. Finally, the reactions that form amines or use amines as a reagent are covered.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Background Information for Amines
    Classification of amines
    Shape
    Properties
    Uses
Nomenclature of Amines
    IUPAC nomenclature
    Common nomenclature
    Amine salts
Synthesis of Amines
    Reduction of nitro compounds
    Reduction of nitriles
    Reduction of amides
    Alkylation of amines
    Reductive amination of aldehydes and ketones
Reactions of Amines
    Reaction with alkyl halides
    Reaction with aldehydes and ketones
    Acylation
    Reaction with sulfonyl chlorides
    Hofmann elimination
    Reaction with nitrous acid

Content Review

Primary Amine
An amine with one alkyl group attached to the nitrogen.

Secondary Amine
An amine with two alkyl groups attached to the nitrogen.

Tertiary Amine
An amine with three alkyl groups attached to the nitrogen.

Quaternary Amine
An amine with four alkyl groups attached to the nitrogen.

IUPAC and Common Nomenclature for Amines
The IUPAC and common nomenclature rules for amines are re-introduced in this tutorial. In addition, a new common nomenclature rule for amine salts are given: Amine salts are named as ammonium salts.

Ways to Synthesize Amines:

1) Reduction of Nitro Compounds
Nitro compounds (those containing $-NO_2$) can be reduced using H_2/catalyst or H^+/metals to primary amines.

2) Reduction of Nitriles
Nitriles are reduced to primary amines with hydrogen and nickel.

3) Reduction of Amides
Amides are reduced to amines using lithium aluminum hydride followed by hydrolysis. The classification of the amine product (primary, secondary, or tertiary) depends on how many carbons were attached to the nitrogen in the amide.

4) Reaction of Alkyl Halides with Amines
Alkyl halides react with ammonia or amines to yield amines.

5) Reductive Amination of Oximes
Aldehydes and ketones react with hydroxylamine and acid to form oximes. Oximes can then be reduced to the amine using several different conditions: hydrogen and nickel; lithium aluminum hydride then H_3O^+, or zinc and hydrochloric acid.

6) Reductive Amination of Imines
Aldehydes and ketones react with primary amines and acid to form imines. Imines can then be reduced to the secondary amine using various conditions: hydrogen and nickel; or lithium aluminum hydride then H_3O^+.

7) Reductive Amination of Enamines
Aldehydes and ketones react with secondary amines and acid to form imines. Imines can then be reduced to the tertiary amine using sodium triacetoxyborohydride.

Key Reactions of Amines:

1) Formation of Ammonium Salts

Amines react with hydrogen halides to form ammonium salts.

2) Formation of Imines

Aldehydes and ketones react with ammonia derivatives and in the presence of acid to form imine derivatives.

3) Formation of Amides

Acid chlorides react with amines to form amides.

4) Sulfonamide Formation

Sulfonyl chlorides react with amines to yield sulfonamides.

5) Hofmann Elimination

Quaternary ammonium halides undergo β-elimination when treated with strong bases to form a tertiary amine and the less substituted alkene.

6) Formation of Arenediazonium Salts

Primary aromatic amines react with nitrous acid (Na_2NO_2) to form arenediazonium salts. These salts are extremely electrophilic so they react readily with various nucleophiles to form a wide range of products.

Sandmeyer Reaction

Reaction of an arenediazonium salt with a copper salt.

18: Infrared and UV Spectroscopy

Chapter Summary

Often in the laboratory, a chemist synthesizes a compound and needs to confirm its structure or is confronted with an unknown compound and needs to determine its structure. Techniques are available to chemists that allow them to determine the structure of a compound. This tutorial covers two such techniques called infrared spectroscopy and UV/Vis spectroscopy.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Basic Information for Infrared
    Background
    Intensity of infrared absorptions
    Bonds with similar infrared absorptions
    Molecular vibrations
    Index of hydrogen deficiency
    Functional groups
Infrared Interpretation Trends
    Zones
    By functional groups
Infrared Absorption Frequency Tables
    Abbreviations
    Frequencies
Infrared Spectra Problem Solving
    Steps
    Examples
Basics of UV/Vis Spectroscopy
    Theory of UV/Vis spectroscopy
    Absorption of UV/Vis light
    Conjugation

Chapter Review

Infrared Spectroscopy

Method of structure determination based upon the amount of infrared light absorbed by a compound.

Index of Hydrogen Deficiency

A calculation that gives the total number of pi bonds and rings present in a molecule from the molecular formula.

Infrared Interpretation Trends
Similar functional groups have similar atoms and will absorb photons of similar energies. In an infrared spectrum, similar functional groups will predictably show absorbances in the same region of the spectrum. Because of this fact, it is possible to scan an IR spectrum and determine the functional groups present in a sample and from that determine the structure of the molecule.

Fingerprint Region
Region of an IR spectrum (1450-400 cm^{-1}) that contains many absorptions specific to a given molecule.

Electronic Spectrum
The spectrum produced when an organic molecule absorbs light in the visible or ultraviolet region that results in an electronic excitation.

Electronic Transition
The movement of a single electron from an occupied orbital to an unoccupied orbital.

HOMO
Highest Occupied Molecular Orbital

LUMO
Lowest Unoccupied Molecular Orbital

Beer-Lambert Law
Law that states the absorption of UV radiation is dependent on the sample, the concentration of the sample, and the size of the sample. The mathematical representation of the law is below:

$$A = \varepsilon c l$$

A = absorbance
ε = molar absorptivity
c = concentration of sample
l = path length

Molar Absorptivity
Measure of how strongly the sample absorbs light at that wavelength.

Conjugation
Alternating single and multiple bonds (either double of triple bonds). Conjugation decreases the energy gap between the HOMO and LUMO energy levels in a molecule.

19: NMR and Mass Spectrometry

Chapter Summary

In the previous tutorial, the student learned about two techniques used by chemists to determine a molecule's structure. Two more techniques are introduced in this tutorial. The first technique, NMR spectroscopy, is a method of structure determination based on the relative position of hydrogens and carbons in spectra. The second technique, mass spectrometry, can help elucidate the molecular formula and structure of a compound by analyzing how the compound fragments after it is hit by electron beam.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Basic Information for NMR
    Background
    Theory
    Definitions
    Index of hydrogen deficiency
Proton NMR Spectroscopy
    Background information
    Splitting of signals
    Proton resonance frequencies tables
    Problem solving
    Examples
Carbon-13 NMR Spectroscopy
    Background information
    Carbon magnetic frequencies tables
    Problem solving
    Examples
Background Information for Mass Spectrometry
    History
    The mass spectrometer
    The molecular ion
    The base peak
    Isotopes and mass spectrometry
The Mass Spectrum
    Fragmentations of alkanes
    Fragmentations of alcohols
    Fragmentations of amines

- Fragmentations of ethers
- Fragmentations of aldehydes and ketones
- The McClafferty rearrangement

Analyzing Mass Spectra

- Guidelines for analysis
- Sample spectra

Chapter Review

Nuclear Magnetic Resonance (NMR) Spectroscopy
Method of structure determination based on the relative positions of hydrogens and carbons in the spectra.

Chemical Shift
The difference in parts per million (ppm) between the frequency of TMS and the frequency of the observed atom.

Tetramethylsilane (TMS)
An internal standard for NMR spectroscopy that has a chemical shift of $\delta 0.00$.

Integration
The area under a peak that is proportional to the number of hydrogens that gave rise to the signal.

Spin-Spin Splitting
A splitting of signals into multiplets when the magnetic field of the proton is affected by protons on adjacent carbons.

Coupling Constant
Distance between the peaks of a multiplet.

Proton NMR Spectroscopy
Type of NMR spectroscopy based on the hydrogen nucleus. In ^1H NMR, the number of signals equals the number of different types of protons present in the molecule. The chemical shift is indicative of the electronic environment of the observed proton and the splitting of the signal indicates the number of protons on adjacent carbons.

Carbon-13 NMR Spectroscopy
Type of NMR spectroscopy based on the carbon-13 nucleus. In ^{13}C NMR, the number of signals equals the number of different types of carbons present. The chemical shift indicates the type of functional group the observed carbon is a part of and the splitting of the signal is determined by the number of hydrogens attached to the observed carbon.

Mass Spectrometry
An analytical tool used to determine the molecular formula and molecular structure for unknown organic compounds.

Molecular Ion
The species formed when the sample molecule loses one electron to become a radical cation. Also known as the parent peak.

Base Peak
The peak in a mass spectrum that is set to 100% relative abundance.

McClafferty Rearrangement
A rearrangement undergone by carbonyl compounds in mass spectrometry. In this rearrangement, the γ hydrogen is abstracted by the carbonyl resulting in the formation of an alkene and an enol.

20: Separations and Purifications

Chapter Summary

As important as synthesizing compounds is in organic chemistry, the separation and purification of these compounds is just as important. There are several techniques that a chemist may use to purify compounds made in the laboratory. This tutorial covers techniques like distillation, extraction, chromatography, and recrystallization.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Extractions
    Theory of extraction
    Liquid-liquid extraction
    Acid-base extraction
Distillation
    Boiling points
    Theory of distillation
    Simple distillation
Chromatography
    Theory of chromatography
    Column chromatography
    Gas-liquid chromatography
    Paper chromatography
    Thin-layer chromatography
Recrystallization
    Theory of recrystallization
    Solvent selection

Chapter Review

Extraction
The process of selectively removing one or more components of a solid, liquid, or gaseous mixture into a separate phase.

Liquid-Liquid Extraction
An extraction where the components of a mixture are partitioned between two immiscible liquids.

Acid-Base Extractions

A type of extraction that is useful for separation of acidic or basic compounds from a mixture.

Distillation
A chemical technique used to separate a component of a mixture from less volatile components on the basis of boiling points.

Boiling Point
The temperature at which the vapor pressure of a liquid is equal to the atmospheric pressure.

Chromatography
The separation of components of a mixture based on their unequal distribution between two immiscible phases.

Column Chromatography
A form of solid-liquid adsorption chromatography.

Eluant
The solvent system used for chromatography.

Gas-Liquid (GC) Chromatography
A common analytical technique used for separating mixtures whose components may differ in boiling point by as little as 0.5 ^{0}C.

Retention Time
The elapsed time from injection of a mixture to detection of the desired component.

Paper Chromatography
A form of solid-liquid chromatography where the stationary phase is a piece of paper.

Retention Factor (R_f Factor)
A physical constant for a compound that can be used for qualitative analysis by comparing the experimental value to standard values. It is calculated by dividing the distance the sample traveled up the chromatography paper by the distance the solvent traveled.

Thin-Layer Chromatography (TLC)
A form of solid-liquid chromatography where the stationary phase is either alumina or silica gel that has been deposited on a glass plate.

Recrystallization
Dissolution of a solid in an appropriate solvent at elevated temperatures and the subsequent reformation of the crystals upon cooling such that any impurities present are left in the solution.

Dielectric Constant
A measure of a solvent’s polarity.

21: Organic Reactions

Chapter Summary

Students will be introduced to more organic terminology in this tutorial with the aim that understanding the terms will translate to a better understanding of organic reactions. Reactions from previous tutorials are also reviewed here.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- Color coded atoms in examples to enable the reader to better follow the action.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Terminology of Organic Reactions
  Mechanism, stoichiometry, thermodynamics, kinetics
  Transition state, activation energy, Hammond postulate
  Kinetic versus thermodynamic control, reactive intermediate, catalyst, solvent effect
Reactions of Alkyl Halides
  Substitution with nucleophiles to form other compounds
  Elimination with KOH to form alkenes
  Reaction with lithium to form alkyl lithiums
  Reaction with magnesium to form Grignard reagents
Reactions of Alkenes
  Addition of HX to form alkyl halides
  Addition of H_2O to form alcohols
  Addition of X_2 to form dihaloalkanes
  Addition of hydrogen to form alkanes
  Oxidation with $KMnO_4$ to form diols
  Oxidation with O_3 to form aldehydes and ketones
Reactions of Alkynes
  Addition of 2 HX to give dihaloalkanes
  Addition of 2 X_2 to give tetrahaloalkanes
  Addition with 2 H_2 to give alkanes
  Oxidation with $KMnO_4$ to give diketones
  Oxidation with O_3 to give carboxylic acids
Reactions of Aromatic Compounds
  Reaction with X_2 and catalyst to give ArX
  Reaction with HNO_3 and H_2SO_4 to give $ArNO_2$
  Reaction with SO_3 and H_2SO_4 to give $ArSO_3H$
  Reaction with RX and $AlCl_3$ to give ArR
  Reaction with R(C=O)X and $AlCl_3$ to give ketones
Reactions of Amines
  Reaction with RX, followed by lost of HX, to yield larger amines

- Reaction with HX, to yield ammonium salts
- Reaction with acid halides to yield amides
- Reaction with sulfonyl chlorides to yield sulfonamides

Reactions of Alcohols
- Reaction with metals to yield alkoxide ions
- Reaction with HX, PX_3, or $POCl_3$ to yield RX
- Reaction with heat and acid to yield alkenes
- Dihalides are treated with 2 KOH to yield alkynes
- Oxidation
- Reaction with RCOOH and acid to yield esters

Reactions of Aldehydes and Ketones
- Reduction to alcohols
- Reduction to alkanes
- Reaction with organometallic reagents to form alcohols
- Reaction with primary amines to yield imines
- Reductive amination to yield amines
- Oxidation of aldehydes to carboxylic acids

Reactions of Carboxylic Acids
- Reduction to alcohols
- Reaction with thionyl chloride to yield acid chlorides
- Reaction with alcohols and acid to give esters
- Reaction with acid halides to give anhydrides

Reactions of Acid Halides
- Hydrolysis to form carboxylic acids
- Reaction with alcohols to form esters
- Reaction with amines to form amides
- Reduction to alcohols
- Reduction to aldehydes
- Reaction with R_2CuLi to form ketones

Reactions of Esters
- Reaction with water and acid to yield carboxylic acids and alcohols
- Reduction to alcohols
- Reaction with amines to yield amides and alcohols

Reactions of Anhydrides
- Hydrolysis of anhydrides to yield carboxylic acids
- Reaction with alcohols to yield esters and carboxylic acids
- Reaction with amines to yield amides and carboxylic acids

Reactions of Amides
- Reaction with aqueous acid to yield carboxylic acids and ammonium ions
- Reaction with water and hydroxide ion to yield carboxylate anions and amines
- Reduction to amines
- Dehydration to nitriles

Chapter Review

Mechanism
Complete step-by-step description of the bond breaking and the bond forming steps of a reaction.

Stoichiometry
The relationship between reactants and products in a chemical reaction.

Thermodynamics
The study of the energy changes that accompany the physical and chemical changes.

Kinetics
The study of the rates of chemical reactions.

Transition State
The energy state between reactants and products.

Activation Energy
The energy needed to initiate a chemical reaction.

Hammond Postulate
States the structure of a transition state is most similar to the structure of the stable species closest to it in energy.

Kinetic versus Thermodynamic Control
In a reaction, the kinetic product predominates at low temperatures while the thermodynamic product predominates at high temperatures.

Reactive Intermediate
A short lived species that is an intermediate in a chemical reaction.

Catalyst
A compound that increases the rate of reaction without being consumed.

Solvent Effect
The effect that a solvent has on the rate of reaction.

Reactions Listed in Tutorial
The reactions in this tutorial are from previous tutorials and are listed for review purposes.

22: Synthesis, Multistep and Retrosynthesis

Chapter Summary:

Multistep synthesis is an important goal of organic chemistry as most molecules can not be made in just one reaction. Different types of multistep syntheses are covered in this tutorial as well as a problem solving process called retrosynthesis analysis that can be used to determine the best synthetic route to a target molecule.

Tutorial Features

- Definition slides introduce terms as they are needed.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

- Principles of Synthesis
    - Definition of synthesis
    - Total synthesis
    - Methodology
- Retrosynthesis
    - Retrosynthetic analysis
    - Disconnections
    - Evaluation

Chapter Review:

Synthesis
Purposeful execution of chemical reactions to get to a desired product.

Synthetic Intermediate
A compound that is a product of one reaction and a starting material for the next reaction.

Total Synthesis
Complete chemical synthesis of complex organic molecules from simple, commercially available precursors.

Linear Synthesis
A type of total synthesis where each reaction produces a synthetic intermediate that is used as a starting material for the next reaction.

Convergent Synthesis
A type of total synthesis where a set of synthetic intermediates are formed. These intermediates are then joined together to form the final product.

Methodology

The development of reactions and methods that give high yields and are reliable for a broad range of substrates.

Retrosynthetic Analysis
A problem-solving technique for transforming the structures of a synthetic target molecule to a sequence of progressively simpler molecules along a pathway that eventually leads to simple, commercially available compounds.

Retrosynthesis
A series of reactions that work backwards from a target molecule to the starting material.

Synthon
A structural unit within a molecule which is related to possible synthetic operations.

Disconnections
Strategic bonds in the target molecule that are potential synthetic linkages.

23: Organic Reaction Mechanisms

Chapter Summary

Understanding reaction mechanisms in organic chemistry enables students to better predict the products obtained in a reaction. In this tutorial, more reaction terminology, mechanism and arrow drawing basics, and criteria for good reaction intermediates are covered. Several reactions from prior tutorials are reviewed in detail with particular attention paid to their mechanisms. The mechanistic details of these reactions illustrate the basic types of reactions common to organic chemistry.

Tutorial Features

- Concept map showing interconnections of new concepts in this tutorial and those previously introduced.
- Definition slides introduce terms as they are needed.
- Step by step mechanisms of key reactions which show the movement of the electrons in the reaction.
- Color coded atoms in examples to enable the reader to better follow the action.
- Visual representation of basic concepts.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

- Terminology in Mechanisms
    - Double headed arrows, heterolytic bond cleavage, heterogenic bond formation
    - Single headed arrows, homolytic bond cleavage, homogenic bond formation
    - Polar reactions
- Substitution Reactions
    - S_n1 reactions
    - S_n2 reactions
- Elimination Reactions
    - E1 reactions
    - E2 reactions
- Mechanism of Addition Reactions
    - Mechanism for the addition of HX to alkenes
    - Mechanism for addition of halogens to alkenes
- Nucleophilic Addition to Carbonyl Compounds
    - Reaction of a Grignard reagent with aldehydes
    - Reaction of aldehydes with primary amines
- Electrophilic Aromatic Substitution
    - Mechanism of electrophilic aromatic substitution
    - Example
- Acid-Base Reactions
    - Deprotonation
    - Protonation
- Carbocation Mechanisms
    - 1,2-Hydride shift
    - 1,2-Alkyl shift

- Anion Mechanisms
  - Mechanism for the alkylation of carbonyl compounds with LDA
  - Mechanism for the addition of the hydride ion
- Radical Reactions
  - Halogenation of alkenes
- Mechanism Basics
  - Understanding mechanisms
- Arrow Drawing Skills
  - Basic arrow drawing skills for heterolytic bonds
  - Examples of nucleophiles
  - Basic arrow drawing skills for homolytic bonds
- Movement of Electrons with Arrows
  - An unshared electron pair becomes a shared electron pair
  - A shared electron pair becomes an unshared electron pair
  - A shared electron pair becomes another shared electron pair
- Intermediates
  - Formation of intermediates
  - Characteristics of good intermediates
  - Characteristics of unlikely intermediates

Chapter Review

Double Headed Arrow
Arrow used to show the movement of a pair of electrons.

Heterolytic Cleavage
A type of bond breaking where one atom involved in the bond receives both electrons while the other atom receives no electrons.

Heterogenic Bond Formation
Bond formation in which one reactant donates both electrons to form the bond.

Single Headed Arrow
Arrow used to show the movement of one electron.

Homolytic Bond Cleavage
A type of bond breaking in which each atom involved in the bond receives one electron.

Homogenic Bond Formation
Bond formation in which each reactant donates an electron to form the bond.

Polar Reaction
A reaction in which a nucleophilic species attacks an electrophilic species.

S_N1 Reaction
Substitution reaction in which a nucleophile attacks an electrophile displacing a leaving group. The reaction proceeds with first order of kinetics and through a carbocation intermediate.

S_N2 Reaction

Substitution reaction in which a nucleophile attacks an electrophile displacing a leaving group. The reaction proceeds with second order kinetics and is a concerted reaction.

Protic Solvents
Solvents that can participate in hydrogen bonding.

Aprotic Solvents
Solvents that can not participate in hydrogen bonding.

Concerted Reactions
Reactions in which all the bond breaking and formation occur in a single step. In contrast to a stepwise reaction involving intermediates.

E1 Reaction
Elimination reaction in which a base deprotonates an alkyl halide displacing a leaving group to form an alkene. The reaction proceeds with first order kinetics and through a carbocation intermediate.

E2 Reaction
Elimination reaction in which a base deprotonates an alkyl halide displacing a leaving group to form an alkene. The reaction proceeds with second order kinetics and is a concerted reaction.

Deprotonation
Reaction in which a base abstracts an acidic hydrogen in a molecule.

Protonation
Reaction in which a molecule gains a proton from an acid.

1,2 Hydride Shift
A carbocation rearrangement in which a hydrogen takes the electrons from the carbon-hydrogen bond it is involved in and moves to an adjacent carbon.

1,2 Alkyl Shift
A carbocation rearrangement in which an alkyl group takes the electrons from the carbon-carbon bond it is involved in and moves to an adjacent carbon.

24: Acid-Base Chemistry

Chapter Summary

In this tutorial you will learn about the definitions of acids and bases including Arrhenius acids and bases, Brønsted-Lowry Theory, Lewis acids and bases. You will also learn about Conjugate acids and bases As well as Equilibria in acid-base reactions. Finally, we will look at molecular structure considerations including Resonance and Inductive effects.

Tutorial Features

- Concept map showing inter-connections of concepts.
- Definition slides introduce terms as they are needed.
- Examples given throughout to illustrate how the concepts apply.
- A concise summary is given at the conclusion of the tutorial.

Key Concepts

Definitions of acids and bases
    Arrhenius acids and bases
    Brønsted-Lowry Theory
    Lewis acids and bases
Conjugate acids and bases
Equilibria in acid-base reactions
Molecular structure considerations
    Resonance in acid-base chemistry
    Inductive effects

Chapter Review

Arrhenius
Acids increase H^+; Bases increase OH^- .

Brønsted-Lowry
Acids donate protons; Bases accept protons.

Lewis
Acids accept a pair of electrons from Bases forming a new covalent bond.

Conjugate Acid-Base Pair
1. **Acid** that donates a proton becomes a **Conjugate Base**
2. **Base** that accepts a proton becomes a **Conjugate Acid**

Acid Strength
Strong acids dissociate complety in aqueous solution:

$$\mathbf{HA_{(aq)} \rightarrow H^+_{(aq)} + A^-_{(aq)}}$$

Weak acid dissociation is an equilibrium process. Stability of A- is key to acid strength:

$$HA_{(aq)} \rightarrow H^{+}_{(aq)} + A^{-}_{(aq)}$$