



Program Applicable  
Effective Quarter: Fall 2018

## I. Catalog Information

CHEM 12A

Organic Chemistry

5 Unit(s)

Prerequisite: CHEM 1C with a grade of C or better.

Advisory: EWRT 1A or EWRT 1AH or ESL 5.

Graded

Lec Hrs: 36.00

Lab Hrs: 72.00

Out of Class Hrs: 72.00

Total Student Learning Hrs: 180.00

An introduction to the physical properties and chemical behavior of important classes of organic compounds, focusing on hydrocarbons and haloalkanes. Emphasis on retrosynthesis, spectroscopic structure determination, and reaction mechanism. Laboratory experiments involving the synthesis of simple compounds and the characterization of those compounds using gas chromatography (GC), and infrared (IR) and nuclear magnetic resonance (NMR) spectroscopy. For chemistry majors or those in closely allied fields such as biochemistry and chemical engineering.

**Course Justification:** This course is a major preparation requirement in the discipline of chemistry at all CSUs and UCs. This course belongs on the Biological Sciences Associates in Sciences degree. This is the first of three courses in the Organic Chemistry sequence of classes where students are introduced to foundational topics in organic chemistry such as nomenclature, functional groups, and simple organic reactions.

- **Student Learning Outcome:** Predict products in reactions of alkanes and haloalkanes by applying concepts from General Chemistry
- **Student Learning Outcome:** Generate logical stepwise reaction mechanisms for simple organic reactions
- **Student Learning Outcome:** Construct molecular structures from IR and <sup>1</sup>H NMR data

## II. Course Objectives

- A. Investigate the essential concepts of molecular structure as applied to organic molecules.
- B. Examine the key structural features and physical properties of important classes of organic compounds, especially alkanes, alkenes, and haloalkanes.
- C. Investigate the role of stereochemistry in chemical reactivity.
- D. Compose valid names for alkanes, alkenes, and haloalkanes using both common and IUPAC nomenclature conventions.
- E. Predict the reactivity of alkanes, alkenes, and haloalkanes on the basis of their structure.

- F. Create detailed reaction mechanisms and use those mechanisms to explain experimental observations or predict the most likely outcome of reactions of alkanes, alkenes, and haloalkanes.
- G. Construct detailed synthetic schemes for the interconversion of alkanes, alkenes, and haloalkanes by functional group transformation using retrosynthetic analysis.
- H. Examine the behavior of alkanes, alkenes, and haloalkanes by utilizing the frameworks of kinetics, thermodynamics, and equilibrium.

### III. Essential Student Materials

None

### IV. Essential College Facilities

Fully equipped chemical laboratory including, at a minimum, the following: consumable chemicals, chemical balances, glassware, molecular models, melting point apparatus, laptops with data acquisition modules, fume hoods, chemical disposal facilities, lockable student storage areas, and laboratory technician.

### V. Expanded Description: Content and Form

- A. Investigate the essential concepts of molecular structure as applied to organic molecules.
  - 1. Investigate bond formation from the perspective of valence bond and molecular orbital theory.
    - a. Electrostatic model of bonding
    - b. Construction of bonding and antibonding molecular orbitals
    - c. Generation of hybrid orbitals
    - d. Sigma and pi bond formation
    - e. Comparison of single, double, and triple bonds
    - f. Bond polarity
  - 2. Predict molecular geometry and corresponding chemical behavior.
    - a. Application of VSEPR theory to molecular shape
      - 1. Methane, ammonia, and water
      - 2. Carbanions
      - 3. Carbocations
      - 4. Radicals
    - b. Molecular polarity
    - c. Electrostatic potential maps (optional)
  - 3. Draw accurate representations of organic molecules.
    - a. Lewis dot structures
      - 1. Formal charge
      - 2. Oxidation state
      - 3. Octet rule

- b. Kekule structures
  - 1. Tetravalent carbon
  - 2. Dash-wedge convention
- c. Depiction of hybrid orbitals
- 4. Examine the effect of resonance on chemical structure.
  - a. Experimental evidence of resonance
  - b. Drawing resonance structures
  - c. Blending of resonance forms as representation of true structure
  - d. Molecular orbital model of delocalization
- B.** Examine the key structural features and physical properties of important classes of organic compounds, especially alkanes, alkenes, and haloalkanes.
  - 1. Identify the major organic functional groups.
    - a. Hydrocarbons - alkanes, alkenes, alkynes
    - b. Saturated substituted hydrocarbons - haloalkanes, alcohols, ethers, amines, thiols, sulfides, disulfides
    - c. Unsaturated substituted hydrocarbons - aldehydes, ketones, imines, enamines, carboxylic acids, esters, amides, nitriles, acyl halides, anhydrides
  - 2. Survey the major physical properties of chemicals.
    - a. Effects of intermolecular forces
    - b. Melting points
    - c. Boiling points
- C.** Investigate the role of stereochemistry in chemical reactivity.
  - 1. Recognize molecular chirality.
    - a. Chirality
      - 1. Handedness
      - 2. Planes of symmetry
      - 3. Non-superimposability
    - b. Optical rotation
      - 1. Plane polarization
      - 2. Polarimetry
    - c. Absolute configuration
      - 1. R and S stereochemical convention
      - 2. Cahn-Ingold-Prelog priority rules
      - 3. r and s pseudo-stereochemical convention (optional)
    - d. Fischer projections (optional)

2. Differentiate between different classes of stereoisomers.
    - a. Enantiomers
    - b. Diastereomers
    - c. Epimers
    - d. Meso compounds
    - e. Anomers (optional)
  3. Examine the effects of chirality on organic reactions.
    - a. Racemic solutions
    - b. Conversion of configuration
      1. Retention of configuration
      2. Inversion of configuration
      3. Loss of configuration
    - c. Syn versus anti addition to multiple bonds
- D.** Compose valid names for alkanes, alkenes, and haloalkanes using both common and IUPAC nomenclature conventions.
1. Examine the guidelines for naming organic compounds based on current IUPAC committee recommendations.
    - a. Overview of substitutive nomenclature
    - b. Identification of parent chain
      1. Substituents
      2. Priority of branches
      3. Naming carbon chains
    - c. Prefixes
      1. Stereochemical signifiers
      2. Numerical multipliers
      3. Position identifiers (locants)
    - d. Substituents
      1. Primary, secondary, tertiary, and quaternary carbons
      2. Primary, secondary, and tertiary substituents
      3. Simple and complex substituents
    - e. Functional group suffixes
    - f. Name construction
      1. Nomenclature syntax
      2. Rules for alphabetization

2. Survey key examples of traditional or common nomenclature.
  - a. Contrasting methods for naming functional groups: Haloalkanes versus alkyl halides
  - b. Common names of common substituents
    1. Isopropyl, isobutyl, sec-butyl, tert-butyl, isopentyl, neopentyl, vinyl, allyl, phenyl, benzyl
    2. Propargyl, crotyl, tert-pentyl (optional)
- E. Predict the reactivity of alkanes, alkenes, and haloalkanes on the basis of their structure.
  1. Assess the likelihood that an organic reaction will occur from the viewpoint of acid/base chemistry.
    - a. Review of essential aspects of acid/base chemistry
      1. Bronsted-Lowry acid/base definition
      2. Lewis acid/base definition
      3. Conjugate pairs
      4. Acid dissociation constants
    - b. Organic acids and bases
      1. Examples of common acidic and basic functional groups
      2. Structural effects on extent of acidity or basicity
    - c. Prediction of reactivity on the basis of pKa values
  2. Examine chemical reactions from the viewpoint of electrostatic potential.
    - a. Bond polarizability
    - b. Nucleophiles and electrophiles
  3. Explore the relationship between the different forms of chemical isomerization and reactivity.
    - a. Structural isomerization
      1. Branched versus unbranched compounds
      2. Constitutional isomers
    - b. Rotomers
      1. Newman projections
      2. Staggered and eclipsed conformers
      3. Steric hindrance and consequential energetic effects
      4. Gauche and anti conformations
      5. Conformational energy diagram
    - c. Cyclic isomers
      1. Ring strain
      2. Chair and boat forms of cyclohexane
      3. Axial and equatorial substitution on cyclohexane

4. Ring inversion of cyclohexane
  5. Conformational analysis of polysubstituted cyclohexanes
  - d. Carbocations
    1. Hyperconjugation
    2. Relative stability
  - e. Alkenes
    1. Cis/trans isomers
    2. E/Z isomers
    3. Relative reactivity
    4. Heats of hydrogenation
  - f. Degree of unsaturation
- F. Create detailed reaction mechanisms and use those mechanisms to explain experimental observations or predict the most likely outcome of reactions of alkanes, alkenes, and haloalkanes.
1. Compare single-electron and electron-pair mechanisms.
    - a. Homolytic versus heterolytic bond cleavage
    - b. Homogenic versus heterogenic bond formation
    - c. Arrow mechanism formalism
  2. Differentiate between major classes of organic reactions.
    - a. Nucleophilic substitution
      1. Unimolecular (SN1) versus bimolecular (SN2) substitution
      2. Comparison of reaction coordinate diagrams for SN1 and SN2 reactions
      3. Rate laws for SN1 versus SN2 reactions
      4. Stereochemical consequences of SN1 versus SN2 reactions
      5. Effects of steric hindrance and carbocation stability on substrate reactivity
      6. Trends of nucleophile reactivity
      7. Trends of leaving group ability
      8. Sulfonates
      9. Solvent effects
    - b. Nucleophilic elimination
      1. Unimolecular versus bimolecular elimination
      2. Effects of substrate structure, nucleophile, and solvent on the likelihood of elimination versus substitution
      3. Zaitsev's rule
      4. Molecular geometry of elimination and effects on elimination in substituted cyclohexanes

5. Bredt's rule
- c. Electrophilic addition
  1. Stepwise mechanism
  2. Markovnikov addition
  3. Carbocation rearrangement
  4. Enantiomer formation
- d. Radical addition
  1. Chain-reaction mechanism
  2. Radical selectivity
  3. Product distribution
  4. Stereochemical consequences
  5. N-Bromosuccinimide
3. Explore the major reactions of alkenes.
  - a. Hydrohalogenation
  - b. Hydrolysis
  - c. Solvolysis
  - d. Bromination
    1. Cyclobromonium ion
    2. Anti addition
    3. Absence of carbocation migration
    4. Halohydrins
  - e. Oxymercuration-demercuration
    1. Cyclomercurinium ion
    2. Reduction of organomercury intermediate
  - f. Hydroboration-oxidation
    1. Borane
    2. Mechanism of cycloaddition
    3. Syn addition
    4. Oxidation of intermediate trialkylborane
    5. Overall anti-Markovnikov conversion of alkenes to alcohols
  - g. Ozonolysis
  - h. Carbenes (optional)
    1. Molozinide formation

2. Decomposition of molozinide to aldehydes, ketones, and carboxylic acids
  - i. Polymerization (optional)
- G. Construct detailed synthetic schemes for the interconversion of alkanes, alkenes, and haloalkanes by functional group transformation using retrosynthetic analysis.
  1. Identify the key changes in functional groups and the carbon backbone that occur during a synthesis.
    - a. Control of stereochemistry
    - b. Control of regiochemistry
  2. Correctly express the reagents and conditions used in a synthetic transformation.
    - a. Incompatibility of acidic and basic reagents
    - b. Expression of reaction conditions such as time, temperature, pressure, and light.
  3. Correctly notate a synthesis comprised of multiple steps.
- H. Examine the behavior of alkanes, alkenes, and haloalkanes by utilizing the frameworks of kinetics, thermodynamics, and equilibrium.
  1. Review core concepts of thermodynamics relevant to organic reactions.
    - a. Enthalpy
      1. Endothermic versus exothermic processes
      2. Hess's law
      3. Heats of reaction
      4. Bond dissociation energy
      5. Heats of formation
    - b. Entropy
    - c. Free energy
      1. Definition of free energy
      2. Relationship to equilibrium constants
      3. Endergonic versus exergonic reactions
  2. Predict the rate of an organic reaction using kinetics.
    - a. Rate laws
      1. Reaction molecularity
      2. Concentration
      3. Rate-limiting step
    - b. Reaction coordinate diagrams
      1. Reactants, products, and intermediates
      2. Activation energy
      3. Transition states



4. Hammond postulate
3. Examine chemical systems at equilibrium.
  - a. Definitions of equilibrium
    1. Dynamic system
    2. Static concentrations
    3. Equal rates of forward and reverse processes
    4. Constancy of energy
  - b. Equilibrium constants
    1. Mathematical form of equilibrium constants
    2. Effect of equilibrium constants on distribution of products versus reactants in a reaction
    3. Acid and base dissociation constants
  - c. Graphical representation of equilibrium
    1. Relationship of idealized reaction coordinate diagrams to equilibrium constants
    2. Representation of equilibrium using reaction progress diagrams

#### VI. Assignments

- A. Required readings from the textbook and laboratory manual
- B. Discretionary written problems from each lecture chapter and laboratory experiment
- C. Written laboratory reports for each experiment performed

#### VII. Methods of Instruction

Lecture and visual aids  
 Laboratory demonstrations  
 Discussion of assigned readings  
 Discussion of problem solving performed in class  
 Quiz and examination review performed in class  
 Homework assignments  
 Collaborative learning and small group exercises  
 Laboratory experience which involves students in formal exercises of data collection and analysis  
 Laboratory discussion sessions and quizzes that evaluate the experiments performed

#### VIII. Methods of Evaluating Objectives

- A. At least three one-hour written examinations designed to periodically assess the students' ability to apply concepts and skills acquired through one of more modes of instruction, such as lecture, assigned readings, small group discussions, or homework problems.
- B. At least one written laboratory examination designed to assess the students' ability to apply concepts and skills acquired through conducting laboratory experiments and preparing written laboratory reports.
- C. Regular homework assignments and/or lecture quizzes designed to periodically assess the students' progress in acquiring key concepts and skills.
- D. Laboratory reports for each experiment performed, which will be used to assess the ability of a

student to clearly and logically express the qualitative or quantitative results of an experiment. Laboratory reports will include an analysis of any relevant spectral or physical data and, optionally, a discussion of theoretical or experimental concepts applied in the experiment.

- E. Comprehensive final lecture exam designed to assess the students' ability to critically apply concepts and skills introduced throughout the course.
- F. One-hour practical final lab examination designed to assess the students' ability to apply concepts and skills acquired through conducting laboratory experiments and preparing written laboratory reports.

#### **IX. Texts and Supporting References**

##### **A. Examples of Primary Texts and References**

1. \*Klein, David. "Organic Chemistry", 3e. Wiley, 2017.
2. \*Gilbert, John C. and Martin, Stephen F. "Experimental Organic Chemistry: A Miniscale and Microscale Approach", 6e. Brooks/Cole, 2015.

##### **B. Examples of Supporting Texts and References**

1. Smith, Janice G. "Study Guide/Solutions Manual for Organic Chemistry", 4e. McGraw-Hill, 2014.

#### **X. Lab Topics**

##### **A. Laboratory Methodology**

1. Maintaining a laboratory notebook
2. Writing laboratory reports

##### **B. Chemical Safety**

1. Materials safety data sheets (MSDS)
2. Chemical disposal
  - a. Separation of waste streams
  - b. Proper disposal methods
  - c. Environmental hazards of improper waste disposal
3. Laboratory environment
  - a. Maintaining laboratory cleanliness
  - b. Chemical labeling
  - c. Segregation of chemicals by hazard
  - d. Secondary containment
4. Personal safety
  - a. Safety goggles
  - b. Limiting chemical exposure
  - c. Safety showers
  - d. Eyewash stations

- e. Proper use of fire extinguishers
5. Emergency situations
- a. Fires
  - b. Earthquakes
  - c. Evacuation procedures
- C. Synthesis and Characterization
1. Separation and purification of organic compounds.
- a. Solvent extraction
  - b. Acid/base extraction
  - c. Recrystallization
  - d. Distillation
2. Chromatography
- a. Thin-layer chromatography (TLC)
    - 1. Mobile and stationary phases
    - 2. Effects of polarity
    - 3. TLC plate development
    - 4. Visualizaion and chemical staining
  - b. Gas chromatography (GC)
3. Physical properties
- a. Melting points
  - b. Boiling points
  - c. Optical rotation
- D. Spectroscopy
1. Overview of spectroscopy
- a. Electromagnetic spectrum
  - b. General design and function of spectrometers
2. Analyze organic compounds using infrared (IR) spectrophotometry.
- a. Experimental set-up
  - b. Molecular vibration and rotation
  - c. Absorbance versus transmittance
  - d. Characteristic IR data for major functional groups
  - e. Interpretation of IR spectra
3. Elucidate the structure of compounds using nuclear magnetic resonance spectroscopy (NMR).

**a. Nuclear spectroscopy**

1. Nuclear spin
2. Active isotopes
3. Magnetic susceptibility
4. Instrument frequency
5. Energy level population
6. Experimental set-up
7. NMR solvents
8. Continuous versus Fourier spectroscopy
9. Acquisition of spectra

**b. Chemical shift**

1. Shielding and deshielding
2. Perturbation of field strength
3. Instrument-independence of chemical shift
4. Chemical shift standards
5. Chemical shift data of common functional groups

**c. Chemical equivalency**

1. Structural equivalency
2. Stereotopic atoms

**d. Time scale**

1. Comparison of speed of acquisition with speed of measured event
2. Temperature-based peak blending of cyclohexanes

**e. Splitting**

1. Origins of chemical splitting
2. Splitting patterns
3. Splitting constants
4. Broadband decoupling

**f. Interpretation of NMR spectra****E. Laboratory Experiments**

1. Recrystallization and melting point of a common organic compound such as benzoic acid, acetanilide, or naphthalene
2. Acid/base extraction of a mixture of organic compounds such as benzoic acid, 4-nitroaniline, and naphthalene
3. Analysis of one or more compounds via thin-layer chromatography (TLC), such as the components of an analgesic

4. Simple and fractional distillation of a mixture of organic compounds such as 1-butanol and 1-hexanol
5. Dehydration of an alcohol, such as 4-methyl-2-pentanol
6. Relative reactivities of haloalkanes in unimolecular and bimolecular substitution
7. Synthesis and characterization of a haloalkane