



## CHEM 211 - ORGANIC CHEMISTRY II

<b>Units Lecture</b>	3.00	<b>Units Lab</b>	2.00	<b>Units Total</b>	5.00
<b>Total Hrs Lecture</b>	49.50	<b>Total Hrs Lab</b>	99.00	<b>Total Course Hrs</b>	148.50

**COURSE DESCRIPTION**

This course continues the one-year organic chemistry sequence begun in CHEM 210. Topics covered include the structure and reactivity of alcohols, aldehydes and ketones, organometallic compounds, carboxylic acids and derivatives, amines and other nitrogen functions, aromatic compounds, sulfur-, phosphorus-, and silicon-containing compounds, heterocyclic compounds, and di- and polyfunctional compounds; conjugation and aromaticity; multistep organic synthesis; and biological chemistry. The course emphasizes the application of organic chemistry reaction mechanisms learned in Chemistry 210 to other compounds. It examines new reactions specific for different functional groups, including alcohols, thiols, aldehydes and ketones, carboxylic acid derivative, aryl halides, and biochemistry-related organic chemistry molecules.

**ENROLLMENT RESTRICTIONS****PREREQUISITES**

CHEM 210 with a grade of "C" or better.

**COREQUISITES****ADVISORIES****OUTLINE OF COURSE CONTENT**

*The course will address the following topics:*

Lecture:

- I. Organometallic compounds
  - A. Carbon-metal bonds in organometallic compounds
  - B. Organometallic nomenclature
  - C. Preparation of organolithium compounds
  - D. Preparation of organomagnesium compounds: Grignard reagents
  - E. Organolithium and organomagnesium compounds as Brønsted bases
  - F. Synthesis of alcohols using grignard reagents
  - G. Synthesis of alcohols using organolithium reagents
  - H. Synthesis of acetylenic alcohols
  - I. Retrosynthetic analysis
  - J. Preparation of tertiary alcohols from esters and grignard reagents
  - K. Alkane synthesis using organocopper reagents
  - L. An organozinc reagent for cyclopropane synthesis
  - M. Carbenes and carbenoids
  - N. Organic derivatives of mercury; oxymercuration-demercuration of alkenes
  - O. Transition metal organometallic compounds.
  
- II. Alcohols, diols, and thiols
  - A. Sources of alcohols
  - B. Preparation of alcohols by reduction of aldehydes and ketones
  - C. Preparation of alcohols by reduction of carboxylic acids and esters
  - D. Preparation of alcohols from epoxides
  - E. Preparation of diols
  - F. Reactions of alcohols: a review and a preview
  - G. Conversion of alcohols to ethers
  - H. Esterification
  - I. Esters of inorganic acids
  - J. Oxidation of alcohols
  - K. Biological oxidation of alcohols
  - L. Oxidative cleavage of vicinal diols
  - M. Preparation of thiols
  - N. Properties of thiols
  - O. Spectroscopic analysis of alcohols



P. Mass spectrometry of alcohols.

III. Ethers, epoxides, and sulfides

- A. Nomenclature of ethers, epoxides, and sulfides
- B. Structure and bonding in ethers and epoxides
- C. Physical properties of ethers
- D. Crown ethers
- E. Preparation of ethers
- F. Williamson ether synthesis
- G. Reactions of ethers: a review and a preview
- H. Acid-catalyzed cleavage of ethers
- I. Preparation of epoxides: a review and a preview
- J. Conversion of vicinal halohydrins to epoxides
- K. Reactions of epoxides: a review and a preview
- L. Nucleophilic ring-opening reactions of epoxides
- M. Acid-catalyzed ring-opening reactions of epoxides
- N. Epoxides in biological processes
- O. Preparation of sulfides
- P. Oxidation of sulfides: sulfoxides and sulfones
- Q. Alkylation of sulfides: sulfonium salts
- R. Spectroscopic analysis of ethers
- S. Mass spectrometry of ethers.

IV. Aldehydes and ketones

- A. Nomenclature
- B. Structure and bonding: the carbonyl group
- C. Physical properties
- D. Sources of aldehydes and ketones
- E. Reactions that lead to aldehydes and ketones: review and applications
- F. Reactions of aldehydes and ketones: a review and a preview
- G. Principles of nucleophilic addition to carbonyl groups: hydration of aldehydes and ketones
- H. Cyanohydrin formation
- I. Acetal formation
- J. Acetals as protecting groups
- K. Reaction with primary amines; nucleophilic addition-elimination
- L. Reaction with secondary amines: enamines
- M. Wittig reaction
- N. Planning an alkene synthesis via the Wittig reaction
- O. Stereoselective addition to carbonyl groups
- P. Oxidation of aldehydes
- Q. Baeyer-Villiger oxidation of ketones
- R. Spectroscopic analysis of aldehydes and ketones
- S. Mass spectrometry of aldehydes and ketones.

V. Enols and enolates

- A. The carbon atom and its hydrogens
- B. A halogenation of aldehydes and ketones
- C. Mechanism of a halogenation of aldehydes and ketones
- D. Enolization and enol content
- E. Stabilized enols
- F. Base-catalyzed enolization, enolate anions
- G. Haloform reaction
- H. Some chemical and stereochemical consequences of enolization



- I. Aldol condensation: aldehydes
- J. Aldol condensation: ketones
- K. Mixed aldol condensations
- L. Aldol condensation in synthetic organic chemistry
- M. Effects of conjugation in  $\alpha, \beta$ -unsaturated aldehydes and ketones
- N. Conjugate nucleophilic addition to  $\alpha, \beta$ -unsaturated carbonyl compounds
- O. Additions of carbanions to  $\alpha, \beta$ -unsaturated ketones: the Michael reaction
- P. Conjugate addition of organocopper reagents to  $\alpha, \beta$ -unsaturated carbonyl compounds
- Q. Alkylation of enolate anions.

- VI. Carboxylic acids
  - A. Carboxylic acid nomenclature
  - B. Structure and bonding
  - C. Physical properties
  - D. Acidity of carboxylic acids
  - E. Salts of carboxylic acids
  - F. Substituents and acid strength
  - G. Ionization of substituted benzoic acids
  - H. Dicarboxylic acids
  - I. Carbonic acid
  - J. Sources of carboxylic acids
  - K. Synthesis of carboxylic acids by the carboxylation of Grignard reagents
  - L. Synthesis of carboxylic acids by the preparation and hydrolysis of nitriles
  - M. Reactions of carboxylic acids: a review and a preview
  - N. Mechanism of acid-catalyzed esterification
  - O. Intramolecular ester formation: lactones
  - P.  $\alpha$ -halogenation of carboxylic acids; Hell-Volhard-Zelinsky reaction
  - Q. Decarboxylation of malonic acid and related compounds
  - R. Spectroscopic analysis of carboxylic acids.

- VII. Carboxylic acid derivatives
  - A. Nomenclature of carboxylic acid derivatives
  - B. Structure of carboxylic acid derivatives
  - C. Nucleophilic acyl substitution in acyl chlorides
  - D. Preparation of carboxylic acid anhydrides
  - E. Reactions of carboxylic acid anhydrides
  - F. Sources of esters
  - G. Physical properties of esters
  - H. Reactions of esters: a review and a preview
  - I. Acid-catalyzed ester hydrolysis
  - J. Base-promoted ester hydrolysis: saponification
  - K. Reactions of esters with ammonia and amines
  - L. Thioesters
  - M. Preparation of amides
  - N. Lactams
  - O. Imides
  - P. Hydrolysis of amides
  - Q. The Hofmann rearrangement of  $N$ -bromo amides
  - R. Preparation of nitriles
  - S. Hydrolysis of nitriles
  - T. Addition of Grignard reagents of nitriles
  - U. Spectroscopic analysis of carboxylic acid derivatives
  - V. Mass spectrometry of carboxylic acid derivatives.



VIII. Ester enolates

- A. Base-promoted ester condensation: Claisen condensation
- B. Intramolecular Claisen condensations: Dieckmann reaction
- C. Mixed Claisen condensations
- D. Acylation of ketones with esters
- E. Ketone synthesis via  $\beta$ -keto esters
- F. Acetoacetic ester synthesis
- G. Malonic ester synthesis
- H. Barbiturates
- I. Michael additions of stabilized anions
- J. A deprotonation of carbonyl compounds by lithium dialkylamides.

IX. Amines

- A. Amine nomenclature
- B. Structure and bonding
- C. Physical properties
- D. Measures of amine basicity
- E. Basicity of amines
- F. Tetraalkylammonium salts as phase-transfer catalysts
- G. Reactions that lead to amines: a review and a preview
- H. Preparation of amines by alkylation of ammonia
- I. Gabriel synthesis of primary alkylamines
- J. Preparation of amines by reduction
- K. Reductive amination
- L. Reactions of amines: a review and a preview
- M. Reactions of amines with alkyl halides
- N. Hofmann elimination
- O. Electrophilic aromatic substitution in arylamines
- P. Nitrosation of alkylamines
- Q. Nitrosation of arylamines
- R. Synthetic transformations of aryl diazonium salts
- S. Azo coupling
- T. Spectroscopic analysis of amines
- U. Mass spectrometry of amines.

X. Aryl halides

- A. Bonding in aryl halides
- B. Sources of aryl halides
- C. Physical properties of aryl halides
- D. Reactions of aryl halides: a review and a preview
- E. Nucleophilic substitution in nitro-substituted aryl halides
- F. Addition-elimination mechanism of nucleophilic aromatic substitution
- G. Related nucleophilic aromatic substitution reactions
- H. Elimination-addition mechanism of nucleophilic aromatic substitution, benzyne
- I. Diels-alder reactions of benzyne.

XI. Phenols

- A. Nomenclature
- B. Structure and bonding
- C. Physical properties
- D. Acidity of phenols
- E. Substituent effects on the acidity of phenols



- F. Sources of phenols
  - G. Naturally occurring phenols
  - H. Reactions of phenols, electrophilic aromatic substitution
  - I. Acylation of phenols
  - J. Carboxylation of phenols, aspirin and the Kolbe-Schmitt reaction
  - K. Preparation of aryl ethers
  - L. Cleavage of aryl ethers by hydrogen halides
  - M. Claisen rearrangements of allyl aryl ethers
  - N. Oxidation of phenols: quinones
  - O. Spectroscopic analysis of phenols.
- XII. Carbohydrates
- A. Classification of carbohydrates
  - B. Fischer projections and the d-l notational system
  - C. Aldotetroses
  - D. Aldopentoses and aldohexoses
  - E. Mnemonic for carbohydrate configurations
  - F. Cyclic forms of carbohydrates: furanose forms
  - G. Cyclic forms of carbohydrates: pyranose forms
  - H. Mutarotation
  - I. Ketoses
  - J. Deoxy sugars
  - K. Amino sugars
  - L. Branched-chain carbohydrates
  - M. Glycosides
  - N. Disaccharides
  - O. Polysaccharides
  - P. Cell-surface glycoproteins
  - Q. Carbohydrate structure determination
  - R. Reduction of carbohydrates
  - S. Oxidation of carbohydrates
  - T. Cyanohydrin formation and carbohydrate chain extension
  - U. Epimerization, isomerizations, and retro-aldol cleavage reactions of carbohydrates
  - V. Acylation and alkylation of hydroxyl groups in carbohydrates
  - W. Periodic acid oxidation of carbohydrates.
- XIII. Acetate derived natural products
- A. Acetyl coenzyme A
  - B. Fatty acids
  - C. Fatty acids biosynthesis
  - D. Phospholipids
  - E. Waxes
  - F. Prostaglandins
  - G. Terpenes, the isoprene rule
  - H. Isopentenyl pyrophosphate: the biological isoprene unit
  - I. Carbon-carbon bond formation in terpene biosynthesis
  - J. Pathway from acetate to isopentenyl pyrophosphate
  - K. Steroids, cholesterol
  - L. Vitamin D
  - M. Bile acids
  - N. Corticosteroids
  - O. Sex hormones
  - P. Carotenoids.



## XIV. Amino acids, peptides, proteins, and nucleic acids

- A. Classification of amino acids
- B. Stereochemistry of amino acids
- C. Acid-base behavior of amino acids
- D. Synthesis of amino acids
- E. Reactions of amino acids
- F. Some biochemical reactions involving amino acids
- G. Peptides
- H. Peptide structure determination: amino acid analysis
- I. Peptide structure determination: sequence analysis
- J. End group analysis: the N-terminus
- K. End group analysis: the C-terminus
- L. Selective hydrolysis of peptides
- M. Strategy of peptide synthesis
- N. Amino group protection
- O. Carboxyl group protection
- P. Peptide bond formation
- Q. Solid-phase peptide synthesis, Merrifield method
- R. Secondary structures of peptides and proteins
- S. Tertiary structures of peptides and proteins
- T. Coenzymes
- U. Protein quaternary structure, hemoglobin
- V. Pyrimidines and purines
- W. Nucleosides
- X. Nucleotides
- Y. Nucleic acids
- Z. Structure and replication of DNA, the double helix
- AA. DNA-directed protein biosynthesis
- BB. DNA sequencing.

## Laboratory:

Chemistry 211 experiments performed in the laboratory portion of the class are designed to complement and support topics presented in lecture. Timing is such that students perform the experiment after the topic has been introduced and developed in lecture so that students are familiar with the subject. During the first 15-20 minutes of the experiment, theory and specifics are addressed. The specific contents of the laboratory are included below:

- I. ChemDraw and Chem3D molecular modeling
- II. Electrophilic aromatic substitution: Friedel-Crafts alkylation
- III. Grignard synthesis: synthesis of benzoic acid and of triphenylmethanol
- IV. Hydrolysis of methylsalicylate and synthesis of acetylsalicylic acid
- V. Williamson ether synthesis
- VI. Aldol condensation
- VII. Aromatic side-chain oxidation: O-chlorobenzoic acid from O-chlorotoluene
- VIII. Synthesis of hippuric from benzoyl chloride and glycine



IX. Diazonium coupling reaction of P-nitrobenzenediazonium sulfate and N, N -dimethylaniline: synthesis of P-(4-nitrobenzeneazo)-N, N-dimethylaniline

X. Reduction of a nitro group: preparation of M-aminoacetophenone

XI. Multi-step synthesis - coenzyme catalyzed synthesis of benzoin and derivatives.

### PERFORMANCE OBJECTIVES

*Upon successful completion of this course, students will be able to do the following:*

- 1). Predict the outcome of organic chemical reactions, based on analyzing the structures of the reactants and conditions of the reaction
- 2). Identify the reagents necessary to carry out organic chemical transformations and syntheses as well as predicting products of reaction
- 3). Show the mechanisms of organic chemical reactions
- 4). Determine the structure of organic compounds using physical and chemical methods of analysis
- 5). Carry out organic chemical reactions and separations in the laboratory followed by a characterization of the reaction products
- 6). Explain the structure and reactivity of organic compounds in terms of bonding theories and electronic structure.

### READING ASSIGNMENTS

*Reading assignments will be consistent with, but not limited by, the following types and examples:*

- 1). Read the appropriate textbook sections to be discussed in lecture. Reading chapter material prior to lecture introduces the student to relevant terminology, structures and names of compounds, and reaction mechanisms
- 2). Read laboratory experiments in order to prepare laboratory notebook prior to coming to lab. Experiments are performed according to procedures written in laboratory notebook
- 3). Read supplemental material for labs including knowing safety considerations based on available MSDS (Material Safety Data Sheets) for all chemical used in laboratory
- 4). Read articles from scientific journals, magazines and reliable Internet sites relevant to current lecture material and labs.

### WRITING ASSIGNMENTS

*Writing assignments will be consistent with, but not limited by, the following types and examples:*

- 1). Prepare short written responses to homework assignments that require analysis and/or assimilation of facts based on textbook readings and/or lecture content
- 2). Document laboratory exercises as written notebook entries while performing each lab activity. After experiment is completed, students write a results and discussion section in their notebook describing what was accomplished during the experiment. A conclusions section for each experiment includes addressing the objectives of the experiment and how the experiment has accomplished those objectives
- 3). Prepare formal written lab reports in scientific journal article format, with references, for selected experiments during the semester.

### OUTSIDE-OF-CLASS ASSIGNMENTS (READING/WRITING/OTHER)

*Outside-of-class assignments will be consistent with, but not limited by, the following types and examples:*

- 1). Complete extensive reading of the textbook for every section covered during lecture
- 2). Read experimental protocols and write in laboratory notebook prior to coming to lab
- 3). Read and understand supplemental experimental material, including MSDS and techniques to be followed during lab
- 4). Perform homework assignments using problems in the text and at the end of every chapter until competency is achieved
- 5). Prepare at least four formal written lab reports in scientific journal format for experiments performed during the semester
- 6). Prepare for essay exams that include definitions, reactions, and interpretation of chemical phenomena.

### STUDENT LEARNING OUTCOMES

#### **Learning Outcome**

1. Students will analyze the structure of a series of organic compounds to explain how their three dimensional geometries influence their rates of reaction.

#### **Mode of Assessment**

1. Written essay question on exam with chemical equations and explanation. Students will be instructed to explain the effects of geometry and their different substitution groups on the rates of reactions like substitution and addition reactions for most organic



- Students will use their knowledge on carbohydrates, mutarotation and Haworth projections to explain why the concentration of one anomer is greater than the other in an aqueous solution.
- Students will use given pKa values of different chemicals as well as their knowledge of structure and resonance concepts to explain what factors determine the strength of an acid.
- Written essay question on exam with chemical equations and explanation. Students will be given 2 anomeric forms of a monosaccharide, like D-glucose, in a Haworth projection and be instructed, starting with a Fischer projection, to explain why the  $\alpha$ -anomer is more stable and has a higher concentration than the  $\beta$ -anomer in aqueous solution.
- Written essay question on exam with chemical equations and explanation. Students will use pKa values of 2 compounds like acetic acid and ethanol, to explain why one (acetic acid) compared to the other (ethanol) will be a much stronger acid. Aside of the pKa values, students will be encouraged to use their knowledge of other concepts like molecular structure and resonance to explain the difference in acid strength.

#### METHODS OF INSTRUCTION

*Instructional methodologies will be consistent with, but not limited by, the following types or examples:*

- Lecture presentation and classroom discussions using the language of chemistry covering the assigned sections from each chapter
- In-class discussion and review of previously covered material solving problems on the board in individual or group activity
- Question and answer sessions for related chemical processes especially as they relate to every-day life.

#### METHODS OF EVALUATION

*Evaluation methodologies will be consistent with, but not limited by, the following types or examples:*

- Questions on exams are designed to reflect critical and creative thinking using essay-type exams
- Quizzes are given weekly covering material recently discussed during lecture to get immediate feedback on understanding of new material
- Laboratory notebooks containing pre-lab questions, procedures used to perform the experiment, and results of the experiment
- At least four formal written lab reports using approved scientific journal article format with references
- Homework problems solved to achieve competency from within each chapter
- Problem solving or skill demonstrations
- Proper understanding for and exercising of correct safety practices in the laboratory
- High level of performance in the laboratory, including coming to the lab prepared, mastering lab techniques, and using the laboratory equipment properly.

#### REQUIRED TEXTBOOKS

*Examples of typical textbooks for this course include the following:*

- Carey, Francis A., and Robert M. Giuliano. Organic Chemistry. 8th ed., McGraw Hill, 2011. ISBN: 978-0073402611
- Bruice, Paula Yurkanis. Organic Chemistry. 6th ed., Prentice Hall, 2010. ISBN: 978-0321663139
- Solomons, T. W. Graham, and Craig B. Fryhle. Organic Chemistry. 10th ed., Wiley, 2009. ISBN: 978-0470401415
- Zubrick, James W. The Organic Chem Lab Survival Manual: A Student's Guide to Techniques. 8th ed., Wiley, 2010. ISBN: 978-0470494370.

#### OTHER REQUIRED INSTRUCTIONAL MATERIALS

- Safety goggles
- Quadrille notebook for lab
- Chemical resistant gloves
- Scientific non-graphing calculator.





**COURSE REPEATABILITY**

***Total Completions Allowed:***

1

***In Combination With:***