Randolph Township Schools
Randolph High School

Organic and Analytical Chemistry II Curriculum

Almost more aspects of life are engineered at the molecular level, and without understanding molecules we can only have a very sketchy understanding of life itself.
Francis Harry Compton Crick

STEM Department
Anthony Emmons

Curriculum Committee
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Curriculum Developed
August, 2018

Date of Board Approval
February 19, 2019

Randolph Township Schools
STEM Department
Organic and Analytical Chemistry II

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Randolph Township Schools
Stem Department
Organic and Analytical Chemistry II

Mission Statement

We commit to inspiring and empowering all students in Randolph schools to reach their full potential as unique, responsible and educated members of a global society.

Randolph Township Schools
Affirmative Action Statement

Equality and Equity in Curriculum

The Randolph Township School district ensures that the district's curriculum and instruction are aligned to the state's standards. The curriculum provides equity in instruction, educational programs and provides all students the opportunity to interact positively with others regardless of race, creed, color, national origin, ancestry, age, marital status, affectional or sexual orientation, gender, religion, disability or socioeconomic status.

N.J.A.C. 6A:7-1.7(b): Section 504, Rehabilitation Act of 1973; N.J.S.A. 10:5; Title IX, Education Amendments of 1972

RANDOLPH TOWNSHIP BOARD OF EDUCATION
EDUCATIONAL GOALS
VALUES IN EDUCATION

The statements represent the beliefs and values regarding our educational system. Education is the key to self-actualization, which is realized through achievement and self-respect. We believe our entire system must not only represent these values, but also demonstrate them in all that we do as a school system.

We believe:

- The needs of the child come first
- Mutual respect and trust are the cornerstones of a learning community
- The learning community consists of students, educators, parents, administrators, educational support personnel, the community and Board of Education members
- A successful learning community communicates honestly and openly in a non-threatening environment
- Members of our learning community have different needs at different times. There is openness to the challenge of meeting those needs in professional and supportive ways
- Assessment of professionals (i.e., educators, administrators and educational support personnel) is a dynamic process that requires review and revision based on evolving research, practices and experiences
- Development of desired capabilities comes in stages and is achieved through hard work, reflection and ongoing growth

Randolph Township Schools
STEM Department
Organic and Analytical Chemistry II

Course Introduction

This is the second semester of a two-part elective sequence designed for high school students interested in studying chemistry beyond the first year requirement. Organic Chemistry studies carbon and the resulting function of natural and man-made carbon based products. Analytical Chemistry studies the separation, identification, and quantification of both natural and man-made products. In order for students to develop an understanding of structure/function relationships, these disciplines of Chemistry are taught simultaneously. This course extends beyond the topics explored in Organic and Analytical Chemistry. Interdisciplinary connections are also made so that students begin to appreciate the many facets of our world on a molecular level.

The Advanced Organic Chemistry curriculum has been written to incorporate the newly adopted New Jersey Student Learning Standards for Science, also known as the Next Generation Science Standards. Within these standards there is a much higher placement of inquiry-based learning which is the method where educators supply students with educational tools but allow them to apply that knowledge through their own agency and investigation. This approach cultivates something that is core to mathematical and scientific thinking which is the application and analysis of data to observed phenomena.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
Curriculum Pacing Chart

SUGGESTED TIME ALLOTMENT	UNIT NUMBER	CONTENT - UNIT OF STUDY
3 weeks	I	Aromatic Compounds
4 weeks	II	Structure Determination and Separation Techniques
3 weeks	III	Organic Halogen Compounds
4 weeks	IV	Carboxylic Acids and Their Derivatives
4 weeks	V	Aldehydes and Ketones

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT I: Aromatic Compounds

<table>
<tr><th>STANDARDS / GOALS:</th><th>ENDURING UNDERSTANDINGS</th><th>ESSENTIAL QUESTIONS</th></tr>
<tr><td rowspan="6">HS-PS1-1:
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2:
Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS2-6:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

.</td><td>Functional groups determine the chemical and physical properties of an organic molecule.</td><td>• What is the role of carbon in the molecular diversity of life?</td></tr>
<tr><td>Resonance energy is the extra stability a compound gains from having delocalized electrons.</td><td>• What determines the relative stability of a compound?</td></tr>
<tr><td>Aromatic compounds undergo electrophilic aromatic substitution reactions.</td><td>• How does electron pushing help in understanding a chemical reaction?</td></tr>
<tr><td>KNOWLEDGE</td><td>SKILLS</td></tr>
<tr><td>Students will know:

Substituents attached to benzene rings can withdraw or donate electrons, which depends on the structure of the substituent.

The most common electrophilic aromatic substitution reactions are halogenation, nitration, sulfonation, and Friedal-Crafts acylation and alkylation.

Once the electrophile is generated, all electrophilic aromatic substitution reactions take place by the same two-step mechanism.</td><td>Students will be able to:

Describe the unusual structural and chemical properties of aromatic compounds.

Predict the products of the electrophilic aromatic substitution reactions showing the orientation and substitution.

Write the mechanism for electrophilic aromatic substitution using the pushing electron technique.</td></tr>
</table>

	The reactivity (stability) of molecules and intermediates is determined by the degree of electron-electron repulsion. Electronic repulsion and withdrawal, along with resonance, are the essential factors in determining the reactivity and the outcome of the reaction. **KEY TERMS:** aromatic compound, Huckel's rule, ortho, meta, para, phenyl group, resonance energy, electrophilic aromatic substitution, sigma complex, activating group, deactivating group, resonance stabilization	Synthesize substituted benzene molecules, while illustrating the orientation of substitution. Draw all the resonance structures for a given molecule. Determine the reactivity and outcome of a given reaction.

ASSESSMENT EVIDENCE: Students will show their learning by:

- Gathering information and citing evidence to support claims during guided inquiry exercises.
- Reflecting on laboratory data and experimental design.
- Conducting partner reviews and completing self-assessments.

KEY LEARNING EVENTS AND INSTRUCTION:

- Synthesis and analysis of aspirin: Students synthesize aspirin and test the product for purity.
- Trinitro-toluene: Synthesize trinitro-toluene from benzene on paper given a list of electrophilic, aromatic substitution reactions.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT I: Aromatic Compounds

SUGGESTED TIME ALLOTMENT	CONTENT-UNIT OF STUDY	SUPPLEMENTAL UNIT RESOURCES
3 weeks	**Unit I: Aromatic Compounds** • Structure of Aromatic Compounds • Properties of Aromatic Compounds • Reactions Involving Aromatic Compounds • Real Life Applications of Aromatic Compounds	Essential Organic Chemistry Paula Yurkanis Bruice (Pages 319-326) Organic Chemistry as a Second Language, 4th Edition David R. Klein Foundations of Organic Chemistry Ron B. Davis Jr. Vial Organic I and II Lab Manual Lab: Synthesis and analysis of aspirin

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT II: Structure Determination and Separation Techniques

STANDARDS / GOALS:	**ENDURING UNDERSTANDINGS**	**ESSENTIAL QUESTIONS**
HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	The interaction of electromagnetic radiation with a molecule enables the determination of the ultimate structure of the molecule.	• How do we interpret physical and chemical data to arrive at a structural formula of an organic compound?
	Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify its composition or determine its purity.	• Why is chemistry considered the enabling science?
	The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms.	• Why are most proton NMR experiments run using solvents containing deuterium instead of hydrogen?
	KNOWLEDGE	**SKILLS**
	Students will know: Spectroscopy is the study of the interaction of matter and electromagnetic radiation. Infrared spectroscopy identifies the kinds of functional groups in a compound. To absorb IR radiation, the dipole moment of the bond must change when the vibration occurs.	**Students will be able to:** Identify simple unknowns given the spectra. Develop and implement a lesson regarding a specific modern spectrometric or separation technique. Use infrared spectroscopy to distinguish functional groups in organic compounds.

	Mass spectrometry allows us to determine the molecular mass and the molecular formula of a compound and some of its structural features. NMR spectroscopy identifies the carbon-hydrogen framework of an organic compound. Gas chromatography, high performance liquid chromatography and supercritical fluid chromatography separate chemical species by taking advantage of the differential strength of intermolecular interactions between and among components. **KEY TERMS:** electromagnetic spectrum, fingerprint region, gas chromatograph, infrared spectrum, mass spectrum, wavelength, wavenumber, magnetic resonance imaging, nuclear magnetic resonance spectroscopy	Explain the theory behind chemical analysis by spectroscopy and describe the various types of electromagnetic radiation in terms of wavelength and frequency. Describe mass spectrometry and use it to determine the molecular and structural formulas. Use proton NMR to elucidate the structure of an organic molecule. Compare different types of chromatography. Analyze the differential strength of intermolecular interactions.

ASSESSMENT EVIDENCE: Students will show their learning by:

- Gathering information and citing evidence to support claims during guided inquiry exercises.
- Reflecting on laboratory data and experimental design.
- Conducting partner reviews and completing self-assessments.

KEY LEARNING EVENTS AND INSTRUCTION:

- Analysis of Esters: Analyze an unknown sample using gas chromatography.
- Mass Spectrometry of Threat Agents: Read article and prepare for class discussion regarding practical uses of mass spectrometry in airport security. https://www.nap.edu/read/10996/chapter/4

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT II: Structure Determination and Separation Techniques

SUGGESTED TIME ALLOTMENT	CONTENT-UNIT OF STUDY	SUPPLEMENTAL UNIT RESOURCES
3 weeks	**Unit II: Structure Determination and Separation Techniques** • Analytical Techniques • Spectroscopy • Infrared Spectroscopy • Mass Spectometry • Real World Applications of Analytical Techniques	Essential Organic Chemistry Paula Yurkanis Bruice (Pages 339-392) Organic Chemistry as a Second Language, 4th Edition David R. Klein Foundations of Organic Chemistry Ron B. Davis Jr. Vial Organic I and II Lab Manual Lab: Analysis of esters

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT III: Organic Halogen Compounds

<table>
<tr><th>STANDARDS / GOALS:</th><th>ENDURING UNDERSTANDINGS</th><th>ESSENTIAL QUESTIONS</th></tr>
<tr><td rowspan="6">HS-PS1-1:
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2:
Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS2-6:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.</td><td>The reactivity of molecules and molecular fragments is determined by the electron distribution associated with the molecule.</td><td>• How do structural features determine the course of a nucleophilic substitution of alkyl halides?</td></tr>
<tr><td>The SN2 reaction is bimolecular, whereas the SN1 reaction is unimolecular.</td><td>• In what ways are unimolecular and bimolecular reactions different? In what ways are they the same?</td></tr>
<tr><td>Tertiary carbocations are more stable than secondary carbocations, which are more stable than primary carbocations.</td><td>• Some elimination reactions are acid-catalyzed. Why are sulfuric and phosphoric acids preferred over hydrochloric or hydro bromic acids?</td></tr>
<tr><td>KNOWLEDGE</td><td>SKILLS</td></tr>
<tr><td>Students will know:

Alkyl halides undergo two kinds of nucleophilic substitution reactions: SN2 and SN1. In both reactions, a nucleophile substitutes for a halogen.

The rate of an SN1 reaction depends on the ease of carbocation formation and the nature of the leaving group.</td><td>Students will be able to:

Draw and name alkyl halides.

Write the products of nucleophilic substitution reactions.

Write SN1 mechanisms showing stereochemistry and describe what controls reaction rates.</td></tr>
</table>

	An SN1 reaction takes place with both inversion and retention of configuration. The E2 reaction is a one-step reaction in which the proton and the halide ion are removed in the same step. In a Diels-Alder reaction, a conjugated diene reacts with a dienophile to form a cyclic compound. The reactivity of the dienophile is increased by electron-withdrawing groups. **KEY TERMS:** saturated, unsaturated, nucleophile, electrophile, inversion of configuration, steric hindrance, hydrogenation, Zaitsev product, Markovnikov's rule	Describe the factors that characterize and control SN1 and SN2 reactions and predict which mechanism will predominate in specific circumstances. Predict the product of a typical E2 reaction and show the mechanism. Predict and draw the structure given the conjugated diene and dienophile. Predict and draw the structure given the conjugated diene with electron-withdrawing groups attached and a dienophile.

ASSESSMENT EVIDENCE: Students will show their learning by:

- Gathering information and citing evidence to support claims during guided inquiry exercises.
- Reflecting on laboratory data and experimental design.
- Conducting partner reviews and completing self-assessments.

KEY LEARNING EVENTS AND INSTRUCTION:

- Synthesis of Tertiary Butyl Chloride: Students will synthesize the molecule and analyze using wet methods. The product is also purified using distillation.
- Substitution Stereochemistry: Predict the stereochemistry of the products for given SN1 and SN2 reactions.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT III: Organic Halogen Compounds

SUGGESTED TIME ALLOTMENT	CONTENT-UNIT OF STUDY	SUPPLEMENTAL UNIT RESOURCES
3 weeks	**Unit III: Organic Halogen Compounds** • Comparing SN2, SN1, E1 and E2 Reactions • Products of Reactions Involving Alkyl Halides • Conjugated Diene and Dienophile • Mechanisms for Substitution and Elimination Reactions	Essential Organic Chemistry Paula Yurkanis Bruice (Pages 263-302) Organic Chemistry as a Second Language, 4th Edition David R. Klein Foundations of Organic Chemistry Ron B. Davis Jr. Vial Organic I and II Lab Manual Lab: Synthesis of tertiary butyl chloride

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT IV: Carboxylic Acids and Their Derivatives

<table>
<tr><th>STANDARDS / GOALS:</th><th>ENDURING UNDERSTANDINGS</th><th>ESSENTIAL QUESTIONS</th></tr>
<tr><td rowspan="8">HS-PS1-1:
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2:
Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS2-6:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.</td><td>A carbonyl group is a carbon double bonded to an oxygen: an acyl group is a carbonyl group attached to an alkyl (R) group.</td><td>• Why do carbonyl compounds undergo nucleophilic additions?</td></tr>
<tr><td>The reactivity of carbonyl compounds resides in the polarity of the carbonyl group.</td><td>• Why are green synthetic methods so important for the environment and our economy?</td></tr>
<tr><td>An ester is a carboxylic derivative because it differs from a carboxylic acid only in the nature of the group that has replaced the OH group of the carboxylic acid.</td><td>• Why are organic acids more closely associated with flavors in wines while esters are more closely associated with aromas?</td></tr>
<tr><td>KNOWLEDGE</td><td>SKILLS</td></tr>
<tr><td>Students will know:

In an acid-catalyzed reaction, all organic reactants are intermediated and products are positively charged or neutral.

In base-catalyzed or -promoted all reactants are negatively charged or neutral.

Carboxylic acids will undergo a nucleophilic acyl substitution reaction.

Green chemistry is the science of designing safer products and processes for a more sustainable future.</td><td>Students will be able to:

Identify acid-catalyzed reactions and predict their outcomes.

Differentiate between acid-catalyzed and base-catalyzed reactions.

Write equations illustrating the reactions of carboxylic acids.

Confirm the composition of benzoic acid by titration using a green method.</td></tr>
</table>

	Green chemistry is the branch of chemistry concerned with developing processes and products to reduce or eliminate hazardous substances. One of the goals of green chemistry is to prevent pollution at its source, as opposed to dealing with pollution after it has occurred. **KEY TERMS:** anhydride, carboxyl group, nucleophilic acyl substitution, oxidation, green chemistry, titration, ester	Compare and contrast a green synthetic route for ibuprofen with one that is not as good for the environment. Synthesize benzoic acid from benzaldehyde using green methodology, which reduces the need for hazardous substances.

ASSESSMENT EVIDENCE: Students will show their learning by:

- Gathering information and citing evidence to support claims during guided inquiry exercises.
- Reflecting on laboratory data and experimental design.
- Conducting partner reviews and completing self-assessments.

KEY LEARNING EVENTS AND INSTRUCTION:

- Synthesis of Isopentyl Acetate- Synthesize an ester that is used in the chemical industry as a banana flavor.
- Green Synthesis of Benzoic Acid - Compare and contrast green synthetic methods with less environmentally-friendly methods.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT IV: Carboxylic Acids and Their Derivatives

SUGGESTED TIME ALLOTMENT	CONTENT-UNIT OF STUDY	SUPPLEMENTAL UNIT RESOURCES
4 weeks	**Unit IV: Carboxylic Acids and Their Derivatives** • Acid- and Base-Catalyzed Reactions • Green Chemistry • Carbonyl and Acyl Groups Within Molecules • Reactions Involving Carboxylic Acids	Essential Organic Chemistry Paula Yurkanis Bruice (Pages 393-430) Organic Chemistry as a Second Language, 4th Edition David R. Klein Foundations of Organic Chemistry Ron B. Davis Jr. Vial Organic I and II Lab Manual Lab: Synthesis of Isopentyl Acetate Lab: Green Synthesis of Benzoic Acid

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT V: Aldehydes and Ketones

<table>
<tr><th>STANDARDS / GOALS:</th><th>ENDURING UNDERSTANDINGS</th><th>ESSENTIAL QUESTIONS</th></tr>
<tr><td rowspan="5">HS-PS1-1:
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2:
Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS2-6:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.</td><td>Electronic and steric factors cause an aldehyde to be more reactive than a ketone toward nucleophilic addition.</td><td>• How does structure affect the behavior and properties of organic molecules?</td></tr>
<tr><td>Nucleophiles that are strong bases, such as hydride ions and Grignard reagents, generally form direct addition products.</td><td>• How is organic chemistry used and applied in the larger world?</td></tr>
<tr><td>KNOWLEDGE</td><td>SKILLS</td></tr>
<tr><td>Students will know:

Grignard reagents react with formaldehyde to form a primary alcohol, with aldehydes to form secondary alcohols, with ketones, esters and acyl halides to form tertiary alcohols, and with carbon dioxide to form carboxylic acids.

Aldehydes, acyl chlorides, esters, and carboxylic acids are reduced by hydride ion to primary alcohols; ketones are reduced to secondary alcohols; and amides are reduced to amines.</td><td>Students will be able to:

Write equations and mechanisms for the Grignard reaction with carbonyl compounds and its use in the synthesis of alcohols.

Describe organometallic compounds and their reactions with carbonyl compounds.

Describe the characteristics that influence the reactivity of the carbonyl group and illustrate the general reactions and mechanisms for nucleophilic addition.</td></tr>
</table>

	KEY TERMS: Grignard reaction, organometallic compound, acyl chloride, ketone, aldehyde, ester, organic synthesis, coupling reaction	

ASSESSMENT EVIDENCE: Students will show their learning by:

- Gathering information and citing evidence to support claim during guided inquiry exercises.
- Reflecting on laboratory data and experimental design.
- Conducting partner reviews and completing self-assessments.

KEY LEARNING EVENTS AND INSTRUCTION:

- Drug Study Tamoxifen: Use inquire skills to synthesize one of the steps in the synthesis of Tamoxifen using a grignard reaction.
- Testing the Effectiveness of Sunscreens: Determine the effectiveness of suntan lotions in screening out UV radiation using the benzopinacol reaction.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II
UNIT V: Aldehydes and Ketones

SUGGESTED TIME ALLOTMENT	CONTENT-UNIT OF STUDY	SUPPLEMENTAL UNIT RESOURCES
4 weeks	**Unit V: Aldehydes and Ketones** • Nucleophiles • Grignard Reactions • Reactions Involving Aldehydes and Ketones • Real World Applications of Aldehydes and Ketones	Essential Organic Chemistry Paula Yurkanis Bruice (Pages 439-460) Organic Chemistry as a Second Language, 4th Edition David R. Klein Foundations of Organic Chemistry Ron B. Davis Jr. Vial Organic I and II Lab Manual Drug study: Tamoxifen Lab: Testing the effectiveness of sunscreen

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II

APPENDIX A

RESOURCES:

Textbook:

Essential Organic Chemistry
Authors: Paula Yurkkanis Bruice
ISBN-13 978-321-93771-1
Copyright 2016 Pearson
Education, Inc.

Technology:

- Software capable of gathering data such as Logger Pro
- Spreadsheet software such as Excel
- Word processor software such as Word
- Presentation software such as PowerPoint

Web Addresses

- **http://www.organic-chemistry.org/namedreactions/**
- **http://www2.chemistry.msu.edu:80/faculty/reusch/VirtTxtJml/nomen1.htm**
- **http://www.ncbi.nlm.nih.gov/pubmed**
- **http://www.chemhelper.com/**
- **http://www.khanacademy.org/**
- **http://www.mhhe.com/physsci/chemistry/atkins**
- **http://epa.gov**
- **http://chemistry.boisestate.edu/people/richardbanks/organic/organicchem.html**
- **http://cdc.gov**
- **http://epa.gov/sustainability/basicinfo.htm**
- **http://epa.gov/climatechange**

Software Names:

- Vernier Probes and Logger Pro
- E-Chem

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II

APPENDIX B

Opportunities exist for interdisciplinary units with courses such as Animal Behavior, Marine Biology and other science electives.

RANDOLPH TOWNSHIP SCHOOL DISTRICT
Organic and Analytical Chemistry II

APPENDIX C

It is assumed that the student has successfully completed Organic and Analytical Chemistry.