

CHEMISTRY

Departmental Notes

Subject Code for Chemistry: **CHEM**

World Wide Web Address: <http://www.chem.queensu.ca/>

Head of Department: Philip Jessop

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Department Manager: Matthew MacArthur

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Chair of Undergraduate Studies: Diane Beauchemin

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Undergraduate Assistant: Meredith Richards

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Graduate Assistant: Michelle Boutilier

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Overview

As one of the top chemistry teaching and research departments in Canada, we offer a stimulating learning environment for undergraduate and graduate students. Queen's Chemistry programs have rich practical laboratory components, where you will put into practice key concepts learned from your lectures. In upper years, you can specialize in one or more of the fundamental branches of chemistry – analytical, inorganic, organic, physical, and theoretical – or explore new applications such as environmental, materials, biological, computational, or polymer chemistry.

Departmental Policies

Safety in the Laboratories

The Departmental Safety Rules are strictly enforced. Everyone is required to wear protective goggles of an approved type at all times in the laboratories. If contact lenses are used, they must be worn underneath protective goggles. Arms, legs, and feet must be covered while working in laboratories. Open-toed shoes (sandals) are not permitted. The use of a laboratory coat is required. Protective gloves may be required.

Students must complete Queen's WHMIS and Safety Awareness training in order to take a laboratory course

in Chemistry. WHMIS and Safety Awareness training will normally be offered during the first two weeks of the Fall Term by the Department of Environmental Health and Safety.

Laboratory Costs

Some chemistry courses require students to purchase a laboratory manual produced in the Department for that particular course. The cost of these manuals will be approximately equal to their cost of production.

A standard scientific calculator (cost of about \$25) is required for use in tests and examinations in many chemistry courses.

Advice to Students

Programs in Chemistry (Overview)

The Department of Chemistry offers a number of Plans, from the Minor (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-minor-arts/>) (30.00 units plus 6.00 supporting units) to the Specialization (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-specialization-science-bs-honours/>) (90.00 units). Students wishing to specialize in chemistry should follow the Major (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-major-science-bs-honours/>) or Specialization Plans (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-specialization-science-bs-honours/>). Students wishing to study chemistry and another subject should consider chemistry as one component of a Major-Minor degree combination, or the Specialization Plan in Environmental Chemistry (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/environmental-chemistry-specialization-science-bs-honours/>) found in the Environmental Studies section of this Calendar.

Second-Year Courses in Organic Chemistry

CHEM 281 and CHEM 282 are intended primarily for students in Life Sciences or Biology Plans who are interested in organic chemistry. Students registered in or considering registering in any Plan in Chemistry or Biochemistry should not enrol in these courses. Organic chemistry is covered in a more integrated fashion in the courses CHEM 211, CHEM 212, CHEM 222, and CHEM 223; approximately 60% of the unit weighting in these courses involves instruction in organic chemistry, as determined by external accreditation. Students who are undecided about their choice of Plan before entering second year are strongly recommended to consult the Chair of Undergraduate Studies in Chemistry. Priority will be



given to students in Chemistry and Biochemistry Plans for enrolment in CHEM 211, CHEM 212, CHEM 213, CHEM 221, CHEM 222, and CHEM 223.

Accreditation by the Canadian Society of Chemistry (CSC)

The Chemistry Major and Chemistry Specialization Plans are fully accredited by the Canadian Society of Chemistry. Students completing these plans will be eligible for membership in the Chemical Institute of Canada and for membership in the various provincial professional chemical associations.

Special Study Opportunities Seminars in Chemistry

The seminar program is an important aspect of departmental offerings although seminars do not carry course credit. They may occur at various times during the week, but Friday (11:30 a.m. - 12:30 p.m.) is the regularly scheduled seminar time. All third- and fourth-year students in chemistry programs are encouraged to attend.

Faculty

For more information, please visit: <https://www.chem.queensu.ca/people> (<https://www.chem.queensu.ca/people/>)

- Diane Beauchemin
- Amanda Bongers
- Stephen Brown
- Chantelle Capicciotti
- John Carran
- Tucker Carrington
- Cathleen Crudden
- Paul Duchesne
- P. Andrew Evans
- Farnaz Heidar-Zadeh
- Simon A. M. Hesp
- Hugh Horton
- Graeme Howe
- Gregory Jerkiewicz
- Philip Jessop
- Igor Kozin
- Lucia Lee
- Guojun Liu
- Michael Mombourquette
- Nicholas Mosey
- Jean-Michel Nunzi

- Richard D. Oleschuk
- Anne Petitjean
- Avena Ross
- Zhe She
- Kevin Stamplecoskie
- Peng Wang
- Gang Wu
- David Zechel

Specializations

- Chemistry – Specialization (Science) – Bachelor of Science (Honours) (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-specialization-science-bs-honours/>)
- Environmental Chemistry – Specialization (Science) – Bachelor of Science (Honours) (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/environmental-chemistry-specialization-science-bs-honours/>)

Major

- Chemistry – Major (Science) – Bachelor of Science (Honours) (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-major-science-bs-honours/>)

Generals/Minors

- Chemistry – General (Arts) – Bachelor of Arts (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-general-arts-ba/>)
- Chemistry – General (Science) – Bachelor of Science (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-general-science-bs/>)
- Chemistry – Minor (Arts) (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-minor-arts/>)
- Chemistry – Minor (Science) (<https://queensu-ca-public.courseleaf.com/arts-science/schools-departments-programs/chemistry/chemistry-minor-science/>)

Courses

CHEM 109 General Chemistry I: From Atoms to Matter Units: 3.00

A quantitative treatment of chemical phenomena and materials. Critical thinking and problem solving are emphasized. Topics include atomic structure and molecular bonding, nomenclature, thermodynamics, phase-transitions and condensed phases. Using information technology, labs, and problem-solving strategies, students will develop an appreciation for the relevance of chemistry to the solution of modern-day societal challenges.

NOTE Not offered at Queen's; only available as a transfer credit.

EXCLUSION CHEM 112; CHEM 113.

Offering Faculty: Faculty of Arts and Science

CHEM 110 General Chemistry II: Thermodynamics and Kinetics Units: 3.00

A quantitative treatment of chemical phenomena and materials. Critical thinking and problem solving are emphasized. Topics include thermodynamics, chemical equilibria, acids and bases, kinetics, electrochemistry and organic reactions. Using information technology, labs, and problem-solving strategies, students will develop an appreciation for the relevance of chemistry to the solution of modern-day societal challenges.

NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

NOTE CHEM 109 and CHEM 110 together, are equivalent to CHEM 112.

Learning Hours: 144 (36 Lecture, 18 Laboratory, 18 Group Learning, 24 Online Activity, 48 Private Study)

Requirements: Prerequisite CHEM 109/3.0. Recommended 4U Chemistry or equivalent. Exclusion CHEM 112/6.0; CHEM 114/3.0.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Understand equilibrium theory and manipulate equilibrium conditions, calculate K and understand how activities are used in the ICE table.
2. Know the second and third laws of thermodynamics, work with and manipulate equations related to entropy and Gibbs energy changes in systems under standard and non-standard conditions.
3. Recognize different types of acids and bases, understand how to manipulate acid/base systems using the ICE table, know the concepts of strong and weak acids and bases.
4. Recognize and calculate first, second and third order rate laws and understand how to manipulate systems to study the kinetics of systems and reaction mechanisms.
5. Understand the basic concepts of oxidation/reduction, electrochemistry and calculate the cell potential of standard and non-standard systems.

**CHEM 112 General Chemistry Units: 6.00**

A survey of modern chemistry: structure and bonding, phases of matter, thermodynamics, acids, bases, electrochemistry, equilibria, kinetics and organic chemistry. Using information technology, labs, and problem-solving strategies, students will develop an appreciation for the relevance of chemistry to the solution of modern-day societal challenges.

NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

NOTE Also offered at Bader College, UK (Learning Hours may vary).

Learning Hours: 288 (72 Lecture, 36 Laboratory, 36 Group Learning, 48 Online Activity, 96 Private Study)

Requirements: Prerequisite None. Recommended 4U Chemistry or equivalent. Exclusion CHEM 109/3.0; CHEM 110/3.0; CHEM 113/3.0; CHEM 114/3.0; CHEM 117/1.5.

Course Equivalencies: CHEM 112B/116B / APSC 131/132

Offering Faculty: Faculty of Arts and Science

CHEM 113 General Chemistry I (with Virtual Laboratory): From Atoms to Matter Units: 3.00

A quantitative treatment of chemical phenomena and materials. Critical thinking and problem solving are emphasized. Topics include atomic structure and molecular bonding, nomenclature, thermodynamics, phase-transitions and condensed phases. The virtual laboratory provides basic practice in different types of chemistry.

NOTE Only offered online, consult Arts and Science Online.

Learning Hours: 126 (72 Online Activity, 54 Private Study)

Requirements: Prerequisite None. Exclusion CHEM 112/6.0. Recommended 4U Chemistry. Note Not normally intended for on-campus degree plans and certificates. Not appropriate for pre and upper level courses that have a laboratory component.

Offering Faculty: Faculty of Arts and Science

CHEM 114 General Chemistry II (with Virtual Laboratory): Thermodynamics and Kinetics Units: 3.00

A quantitative treatment of chemical phenomena and materials. Critical thinking and problem solving are emphasized. Topics include thermodynamics, chemical equilibria, acids and bases, kinetics, electrochemistry and organic reactions. The virtual laboratory provides basic practice in different types of chemistry.

NOTE Only offered online, consult Arts and Science Online.

Learning Hours: 126 (72 Online Activity, 54 Private Study)

Requirements: Prerequisite CHEM 113/3.0. Exclusion CHEM 112/6.0. Note Not normally intended for on-campus degree plans and certificates. Not appropriate for pre and upper level courses that have a laboratory component.

Offering Faculty: Faculty of Arts and Science

CHEM 117 General Chemistry Laboratory Units: 1.50

Laboratory course intended for students who have taken CHEM 113 and CHEM 114 online and wish to add a laboratory component (i.e., that of CHEM 112) that affords foundational experience in different types of chemistries (physical, analytical, etc.) through experiments in thermodynamics, neutralization, electrochemistry, equilibria, kinetics and organic chemistry.

NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

Learning Hours: 84 (36 Laboratory, 48 Private Study)

Requirements: Prerequisite CHEM 114/3.0. Exclusion CHEM 112/6.0.

Course Equivalencies: CHEM 117, CHEM 117B

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Analyze experimental data critically.
2. Do error analysis and reporting.
3. Better understand some of the first-year chemistry material.
4. Understand equipment principles and limitations.
5. Understand and use concepts of equilibrium systems including acid/base, solubility, oxidation/reduction and precipitation systems.
6. Determine and describe the kinetics of a system using different experimental procedures and relate the results to reaction mechanisms.

CHEM 211 Main Group Chemistry Units: 3.00

An introduction to chemistry of main group inorganic and organic compounds with the use of fundamental quantum mechanics, molecular orbital diagrams and Lewis structures to describe the structure and bonding. The stereochemistry and chirality of organic compounds, solid state inorganic chemistry, and descriptive chemistry of compounds of the main group elements will be covered. The laboratory will introduce skills in inorganic and organic synthesis.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 144 (36 Lecture, 36 Laboratory, 9 Tutorial, 63 Private Study)

Requirements: Prerequisite (CHEM 109/3.0 and CHEM 110/3.0) or CHEM 112/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 212 Principles of Chemical Reactivity Units: 3.00

An introduction to the kinetics and mechanisms of reactions in gaseous and condensed phases, including acid-base and nucleophilic substitution reactions at carbon and other main group centers. Other topics will include molecular dynamics and reactions in solution. The laboratory illustrates measurement techniques and develops laboratory skills. NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

Learning Hours: 126 (36 Lecture, 18 Laboratory, 9 Tutorial, 63 Private Study)

Requirements: Prerequisite ([CHEM 109/3.0 and CHEM 110/3.0] or CHEM 112/6.0) and (MATH 120/6.0 or MATH 121/6.0 or [MATH 123/3.0 and MATH 124/3.0] or MATH 130/3.0). Exclusion CHEM 281/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 213 Introduction to Chemical Analysis Units: 3.00

Introduction to analytical chemical methods and science. Topics include statistical analysis of data, titrations and equilibrium theory, spectrophotometry and instrumental elemental analysis.

NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

Learning Hours: 144 (36 Lecture, 36 Laboratory, 9 Tutorial, 63 Private Study)

Requirements: Prerequisite (CHEM 109/3.0 and CHEM 110/3.0) or CHEM 112/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 221 Material, Solutions, and Interfaces Units: 3.00

A survey of the thermodynamic properties of gases and liquids, including phase and chemical equilibria and electrochemistry. An introduction to the properties of materials, interfaces, surfaces and aqueous solutions. The laboratory uses modern software to facilitate equilibrium calculations, illustrates measurement techniques and develops laboratory skills.

NOTE Laboratory Equipment (Lab Coat, Goggles, Blue Lab Book): estimated cost \$67.

Learning Hours: 126 (36 Lecture, 18 Laboratory, 18 Tutorial, 54 Private Study)

Requirements: Prerequisite ([CHEM 109/3.0 and CHEM 110/3.0] or CHEM 112/6.0) and (MATH 120/6.0 or MATH 121/6.0 or [MATH 123/3.0 and MATH 124/3.0]).

Offering Faculty: Faculty of Arts and Science

CHEM 222 Methods of Structure Determination Units: 3.00

A survey of practical spectroscopic and spectrometric methods for the determinations of the structures of organic and inorganic compounds. Methods will include nuclear magnetic resonance, electronic, infrared/Raman spectroscopy, and mass spectrometry. Tutorials will involve solving compound structures using spectroscopic data, and include an introduction to computational methods in spectroscopy.

Learning Hours: 126 (36 Lecture, 18 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 112/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 223 Organic Reactions Units: 3.00

Mechanistically oriented study of organic reactions with emphasis on applications to synthesis. The laboratory affords experience in organic synthesis.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 144 (36 Lecture, 36 Laboratory, 9 Tutorial, 63 Private Study)

Requirements: Prerequisite CHEM 211/3.0 and CHEM 212/3.0. Exclusion CHEM 282/3.0; CHEM 285/3.0.

Offering Faculty: Faculty of Arts and Science



CHEM 224 Mathematical Tools for Chemical Problems Units: 3.00

This course aims at providing chemistry students with mathematical skills that are borrowed from Calculus and Linear Algebra, which are necessary to explore kinetics, quantum chemistry, and spectroscopy. The course will be based on chemically-relevant problems.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite (CHEM 109/3.0 and CHEM 110/3.0) or CHEM 112/6.0. Recommended MHF4U and MCV4U or equivalent, or 4U AFIC, or permission of the Department.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Translate chemical problems into mathematical language, determine which mathematical tools are useful for which problem.
2. Use the mathematical methods (especially linear algebra and (multivariate) calculus) that are most relevant for chemical problems.
3. Interpret chemical phenomena through mathematical modelling.
4. Identify which types of chemical problems can be understood using mathematical tools and apply the appropriate tools.
5. Identify, and correct, imprecise and incorrect mathematical reasoning and statistical fallacies.
6. Present mathematical concepts and tools required for quantum chemistry and spectroscopy courses.
7. Explain how mathematical models are used in chemistry.

CHEM 281 General Organic Chemistry I (with Virtual Laboratory) Units: 3.00

An introduction to the basic principles of organic chemistry with emphasis on bonding, stereochemistry, reaction intermediates and reaction mechanisms, and structure-reactivity correlations. Intended for students in biological and life sciences. Students in chemistry or biochemistry programs should not enrol in this course.

NOTE Molecular Model Set: estimated cost \$26.

NOTE Also offered online, consult Arts and Science Online (Learning Hours may vary).

Learning Hours: 108 (36 Lecture, 24 Online Activity, 48 Private Study)

Requirements: Prerequisite (CHEM 109/3.0 and CHEM 110/3.0) or CHEM 112/6.0 or CHEM 114/3.0. Exclusion CHEM 212/3.0. Note Students in BCHM or CHEM programs should not enrol in this course.

Offering Faculty: Faculty of Arts and Science

CHEM 282 General Organic Chemistry II Units: 3.00

A continuation from CHEM 281 intended for students in biological sciences, life sciences, and other programs taking no further courses in organic chemistry. Students in chemistry or biochemistry programs should not enrol in this course. Organic molecules and their reactions; relevance to biological systems. Illustrations using biomolecules such as carbohydrates, amino acids and proteins, lipids, and nucleic acids. The laboratory affords experience in elementary organic syntheses.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 141 (36 Lecture, 33 Laboratory, 12 Online Activity, 60 Private Study)

Requirements: Prerequisite ([CHEM 109/3.0 and CHEM 110/3.0] or CHEM 112/6.0) and CHEM 281/3.0.

Exclusion CHEM 223/3.0; CHEM 285/3.0. Note Students in BCHM or CHEM programs should not enrol in this course.

Offering Faculty: Faculty of Arts and Science

CHEM 285 General Organic Chemistry II (with Virtual Laboratory) Units: 3.00

A continuation from CHEM 281 intended for students in biological sciences, and other plans taking no further courses in organic chemistry. Students in chemistry or biochemistry plans should not enrol in this course. Organic molecules and their reactions; relevance to biological systems. Illustrations using biomolecules such as carbohydrates, amino acids and proteins, lipids, and nucleic acids. The virtual laboratory provides knowledge of elementary organic syntheses.

NOTE Only offered online, consult Arts and Science Online.

Learning Hours: 99 (60 Online Activity, 39 Private Study)

Requirements: Prerequisite CHEM 281/3.0. Exclusion CHEM 223/3.0; CHEM 282/3.0. Note Students in CHEM, BCHM, or LISC (Hons) programs should not enrol in this course.

Offering Faculty: Faculty of Arts and Science

**CHEM 286 General Organic Chemistry II
(Laboratory) Units: 1.50**

Laboratory course intended for students in biological sciences, life sciences, and other programs who have taken CHEM 285, and wish to add a laboratory component (i.e., that of CHEM 282) that affords experience in elementary organic syntheses, and do not intend to take any further courses in organic chemistry.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 77 (33 Laboratory, 44 Private Study)

Requirements: Prerequisite CHEM 285/3.0. Exclusion CHEM 223/3.0; CHEM 282/3.0. Note Students in BCHM or CHEM programs should not enrol in this course.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Conduct laboratory experiments that focus on performing chemical reactions relevant to synthesis, extraction and other purification techniques, chemical tests for functional groups, and the characterization of organic compounds.
2. Critically analyze scientific results.
3. Critically communicate scientific results.

CHEM 311 Mechanistic Organic Chemistry Units: 3.00

Fundamental mechanistic concepts of organic reactions, structure-activity relationships, solvent effects and catalysis. Mechanistic aspects of substitution, addition, elimination and pericyclic reactions.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0 or CHEM 282/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 312 Transition Metal Chemistry Units: 3.00

Introduction to the chemistry, bonding and structures of coordination compounds of the transition metals; transition metals in the solid state and in biological systems; industrial and environmental aspects of transition metal chemistry.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 211/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 313 Quantum Mechanics Units: 3.00

Elementary principles and applications of wave mechanics with special reference to molecular orbitals and chemical bonding.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite (CHEM 211/3.0 or CHEM 222/3.0) and (CHEM 224/3.0 or MATH 110/6.0 or MATH 111/6.0* or MATH 112/3.0) and (MATH 120/6.0 or MATH 121/6.0 or [MATH 123/3.0 and MATH 124/3.0]) and (PHYS 104/6.0 or PHYS 106/6.0 or [PHYS 115/3.0 and PHYS 116/3.0] or PHYS 117/6.0). One-Way Exclusion May not be taken with or after PHYS 344/3.0.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Explain the postulates and general principles of quantum mechanics.
2. Solve the Schrödinger equation for systems such as the particle in a box, harmonic oscillator, rigid rotor, and the Hydrogen atom.
3. Apply the variational method and perturbation theory to chemical systems.
4. Apply quantum mechanics to describe the electronic structure of molecules and calculate molecular properties.
5. Provide a quantum-mechanical description for chemical concepts such as atomic and molecular orbitals.

**CHEM 314 Strategies in Organic Synthesis Units: 3.00**

One further step in mastering synthetic organic chemistry. Building on knowledge of introductory organic reactivity, essential principles underlying strategies in synthetic organic chemistry will be covered, with an emphasis on regio- and stereo-controls.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0 or CHEM 282/3.0. Corequisite CHEM 311/3.0.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Integrate knowledge from different functional groups, analyze their interplay, allowing to complete a reaction sequence, towards total synthesis.
2. Plan synthetic sequences taking advantage of the regioselectivity and stereoselectivity of reactions reviewed in 2nd and 3rd year Organic Chemistry courses.
3. Predict products of a reaction sequence, including which major regioisomer(s) and/or stereoisomer(s) are formed.
4. Write complete reaction mechanisms, identify rate-determining step and relevant transition-state, in order to justify the outcome of a particular reaction.
5. Research and present reactions related to carbonyl chemistry, cycloadditions, heterocyclic chemistry and radical transformations (extensions to other type of chemistry may also apply).

CHEM 321 Instrumental Chemical Analysis Units: 3.00

Overview of instrumental methods of chemical analysis. Topics include gas and liquid chromatography, mass spectrometric detection, new separation methods, electrochemical analysis, inductively coupled plasma-based elemental analysis.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 213/3.0. Exclusion ENSC 471/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 322 The Chemical Bond: Computation and Spectroscopy Units: 3.00

The application of quantum mechanics to the structures and internal motions of molecules. The foundations of electronic, vibrational, rotational and NMR spectroscopy will be discussed together with their applications.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 313/3.0 or PHYS 344/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 323 Biological Chemistry Units: 3.00

Introduction to the chemical basis of biological systems and biomolecules, protein structure and synthesis, enzyme catalysis, nucleic acids (DNA, RNA), carbohydrates, membranes, cell signalling, biosynthetic and metabolic pathways.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0 or CHEM 282/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 326 Environmental and Green Chemistry Units: 3.00

The first part examines chemical contaminants in the atmosphere, water, soils and sediments, including sources, behaviour, transport, and distribution among these environments. The second part introduces Green Chemistry, examining industrial sources of contaminants and the modification of industrial processes in order to minimize environmental impact.

Learning Hours: 108 (33 Lecture, 3 Group Learning, 72 Private Study)

Requirements: Prerequisite ([CHEM 223/3.0 or CHEM 281/3.0] and 6.0 units of CHEM at the 200-level).

Offering Faculty: Faculty of Arts and Science

CHEM 347 Applied Surface and Colloid Science Units: 3.00

The course covers four major topics.

1. The thermodynamic properties of interfaces (surface energy, wetting, surface area and porosity, capillary effects, work of adhesion/cohesion).
2. Models of adsorption/desorption phenomena.
3. The dynamics of phase transitions (meta-stability, nucleation, spinoidal decomposition).
4. The stability and characterization of colloidal systems. Student appreciation for the importance of these phenomena is cultivated using examples drawn from industrial processes/products including inks, paints, foods, polymer blends, and nanocomposites.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 221/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 397 Experimental Chemistry Units: 6.00

Laboratory course introducing modern experimental methods in chemistry, including synthesis, analytical instrumentation and computational methods. The integration of several methods will be emphasized in the synthesis and characterization of molecules.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 300 (144 Laboratory, 12 Tutorial, 144 Private Study)

Requirements: Prerequisite CHEM 222/3.0 and CHEM 223/3.0 and 6.0 units of CHEM at the 200-level. Corequisite 6.0 units of CHEM at the 300-level. Exclusion CHEM 398/3.0; CHEM 399/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 398 Experimental Chemistry I Units: 3.00

Laboratory course. In consultation with the course coordinator, and subject to availability, students may select experiments as are relevant to their degree program including synthesis, analytical instrumentation and computational methods. The integration of several methods will be emphasized in the design and characterization of molecules.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 156 (72 Laboratory, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 222/3.0 and CHEM 223/3.0 and 3.0 units of CHEM at the 200-level. Corequisite 3.0 units of CHEM at the 300-level. Exclusion CHEM 397/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 399 Experimental Chemistry II Units: 3.00

Laboratory course. In consultation with the course co-coordinator, and subject to availability, students may select experiments as are relevant to their degree program including synthesis, analytical instrumentation and computational methods. The integration of several methods will be emphasized in the design and characterization of molecules.

NOTE Laboratory Equipment (Lab Coat, Goggles, Carbon Lab Book): estimated cost \$73.

Learning Hours: 156 (72 Laboratory, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 222/3.0 and CHEM 223/3.0 and 3.0 units of CHEM at the 200-level. Corequisite 3.0 units of CHEM at the 300-level. Exclusion CHEM 397/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 411 Advanced Analytical Chemistry Units: 3.00

A discussion of recent advances in analytical chemistry and its applications to the environmental, materials and biomedical fields. At least four topics will be covered from sample preparation, separation methods, multidimensional chromatography, elemental spectroscopy, mass spectroscopy, and surface analysis methods. Additional topics will be selected from the current literature.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 213/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 412 Statistical Mechanics Units: 3.00

The fundamentals of statistical mechanics with applications to thermodynamic properties of gases, liquids and solids and to chemical equilibrium in dilute gases.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite (CHEM 221/3.0 and CHEM 313/3.0) or (PHYS 345/3.0 and PHYS 372/3.0). Exclusion PHYS 472/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 413 Computational Chemistry Units: 3.00

The application of quantum mechanics to chemical structures, energetics, internal motions of molecules, and chemical reactions. An introduction to the use of modern electronic structure software in chemistry.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 313/3.0 or PHYS 345/3.0.

Offering Faculty: Faculty of Arts and Science

**CHEM 414 Catalysis Units: 3.00**

An advanced treatment of the concepts and applications of catalysis, including the kinetics of catalysis and topics selected from the areas of homogeneous, heterogeneous, and biocatalysis.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0 and CHEM 312/3.0.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Identify the specific role of a catalyst in a transformation and thereby predict the outcome of the combination of one or more catalyst.
2. Draw complete catalytic cycle for important reactions having been able to decipher the appropriate mechanism.
3. Rationalize the outcome of a particular reaction in the context of chemo-, regio- and stereoselectivity based on the catalyst combination.
4. Develop proficiency at reading and searching the primary chemical literature and using relevant search engines, Google Scholar, SciFinder, etc.
5. Identify potential problems with specific catalytic combinations.

CHEM 415 Electrochemistry and Electrocatalysis Units: 3.00

The course covers concepts of equilibrium electrochemistry and examines the structure of the electrode-solution interface. It discusses the basics of electron transfer and derives electrochemical kinetics equations. It shows examples of several electrochemical reactions and overviews experimental methods used to study electrochemical phenomena.

Learning Hours: 120 (36 Lecture, 12 Online Activity, 72 Private Study)

Requirements: Prerequisite CHEM 212/3.0 and CHEM 221/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 416 Advanced Biological and Bioanalytical Chemistry Units: 3.00

An advanced discussion of the chemical basis of biologically relevant molecules, pathways and methods of their characterization. Topics covered will draw from advanced properties, characterization and application of DNA/RNA, proteins/peptides, lipids, carbohydrates, alkaloids, terpenes and polyketides and bioanalytical/molecular biology techniques.

Learning Hours: 120 (33 Lecture, 3 Seminar, 12 Online Activity, 72 Private Study)

Requirements: Prerequisite CHEM 323/3.0 or BCHM 310/9.0 or (BCHM 315/3.0 and BCHM 316/3.0).

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Propose reasonable chemical mechanistic hypotheses for production of biomolecules.
2. Evaluate and articulate appropriate chemical analytical and bioanalytical techniques for investigating biomolecule structure, function and application.
3. Develop an appreciation of how chemistry can be applied to study biomolecules, and how biomolecules can be synthesized or produced using molecular biology tools.
4. Apply their understanding of biomolecule synthesis and production, and chemical/bioanalytical techniques, to new topic areas within biological chemistry, assessment of the new topic will include an analysis of the contribution of indigenous knowledge and the impact of colonial science.

CHEM 421 Advanced Methods in Physical Chemistry Units: 3.00

Modern spectroscopic methods for the structural and electronic characterization of molecules will be discussed, including: NMR, X-ray and synchrotron-based spectroscopies, laser spectroscopy, surface spectroscopic methods and scanning probe methods.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 313/3.0 or PHYS 345/3.0. Corequisite CHEM 322/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 422 Synthetic Organic Chemistry Units: 3.00

Modern synthetic methods in organic chemistry. Principles of strategy in planning organic syntheses based on simple classifications of reagents and reactions, and on the control of stereochemistry.

Learning Hours: 120 (36 Lecture, 12 Tutorial, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0.

Offering Faculty: Faculty of Arts and Science

Course Learning Outcomes:

1. Rationalize the outcome of a particular transformation in the context of chemo-, regio- and stereoselectivity.
2. Draw reaction mechanisms for specific reactions through the identification of the type of process.
3. Be Proficient at searching the chemical literature using SciFinder, etc.
4. Design the stereoselective synthesis of small molecules.
5. Develop selection skills for suitable reaction conditions for a specific transformation.
6. Diagnose potential problems in synthetic reactions and sequences.

CHEM 423 Topics in Inorganic and Organometallic Chemistry Units: 3.00

An examination of aspects of modern inorganic and organometallic chemistry. Topics will include metal-ligand bonding in organometallic complexes, applications of organometallics in organic synthesis, metal-metal bonding in dinuclear and polynuclear metal complexes, and may include reaction mechanisms of transition metal complexes, bioinorganic chemistry, and symmetry.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 312/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 424 Polymer Chemistry Units: 3.00

Specific properties of polymers (glass transition, crystallinity, polydispersity, etc.) and their dependence on macromolecular structure and isomerism. Polymer synthesis overview: step and chain polymerization (free-radical, ionic and insertion mechanisms) and reactions on polymers. Examples of polymers and their uses.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 223/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 425 Self-Assembly and Materials Units: 3.00

Four topics covering a range of self-assembled molecular systems will be discussed: monolayers and bilayers, block co-polymers, nanoparticles, and liquid crystals. Material properties, synthetic methods and application of these systems in current and emerging technologies, including nanotechnologies, will be covered.

Learning Hours: 108 (36 Lecture, 72 Private Study)

Requirements: Prerequisite CHEM 221/3.0 and CHEM 223/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 497 Research Project Units: 6.00

A full-year research project on a topic in chemistry, supervised by a member of staff. Normally limited to students in the final year of a major or subject of specialization concentration in Chemistry. May be taken in the Summer Term with permission. Additional restrictions may apply.

NOTE Laboratory Equipment (Lab Coat, Goggles): estimated cost \$55.

Learning Hours: 240 (216 Laboratory, 24 Private Study)

Requirements: Prerequisite CHEM 397/6.0. Exclusion CHEM 498/3.0; CHEM 499/3.0.

Offering Faculty: Faculty of Arts and Science

CHEM 498 Research Project I Units: 3.00

A Fall Term research project on a topic in chemistry, supervised by a member of staff. Normally limited to students in the final year of a major or subject of specialization in Chemistry. Additional restrictions may apply.

Learning Hours: 120 (108 Laboratory, 12 Private Study)

Requirements: Prerequisite Permission of the Department. Exclusion CHEM 497/6.0.

Offering Faculty: Faculty of Arts and Science

CHEM 499 Research Project II Units: 3.00

A Winter Term research project on a topic in chemistry, supervised by a member of staff. Normally limited to students in the final year of a major or subject of specialization in Chemistry. Additional restrictions may apply.

Learning Hours: 120 (108 Laboratory, 12 Private Study)

Requirements: Prerequisite Permission of the Department. Exclusion CHEM 497/6.0.

Offering Faculty: Faculty of Arts and Science

**CHEM 594 Independent Study Units: 3.00**

Exceptionally qualified students entering their third- or fourth-year may take a program of independent study provided it has been approved by the Department or Departments principally involved. The Department may approve an independent study program without permitting it to be counted toward a concentration in that Department. It is, consequently, the responsibility of students taking such programs to ensure that the concentration requirements for their degree will be met.

NOTE Requests for such a program must be received one month before the start of the first term in which the student intends to undertake the program.

Requirements: Prerequisite Permission of the Department or Departments principally involved.

Offering Faculty: Faculty of Arts and Science

CHEM 595 Independent Study Units: 6.00

Exceptionally qualified students entering their third- or fourth-year may take a program of independent study provided it has been approved by the Department or Departments principally involved. The Department may approve an independent study program without permitting it to be counted toward a concentration in that Department. It is, consequently, the responsibility of students taking such programs to ensure that the concentration requirements for their degree will be met.

NOTE Requests for such a program must be received one month before the start of the first term in which the student intends to undertake the program.

Requirements: Prerequisite Permission of the Department or Departments principally involved.

Offering Faculty: Faculty of Arts and Science

CHEM 598 Independent Study Units: 9.00

Exceptionally qualified students entering their third- or fourth-year may take a program of independent study provided it has been approved by the Department or Departments principally involved. The Department may approve an independent study program without permitting it to be counted toward a concentration in that Department. It is, consequently, the responsibility of students taking such programs to ensure that the concentration requirements for their degree will be met.

NOTE Requests for such a program must be received one month before the start of the first term in which the student intends to undertake the program.

Requirements: Prerequisite Permission of the Department or Departments principally involved.

Offering Faculty: Faculty of Arts and Science