CHED MEMORANDUM ORDER (CMO)
No. 08
Series 2011

SUBJECT: POLICIES AND STANDARDS FOR THE MASTER OF SCIENCE IN CHEMISTRY (M.Sc. Chemistry) and MASTER OF CHEMISTRY (M. Chemistry)

In accordance with the pertinent provisions of Republic Act (RA) No. 7722, otherwise known as the "Higher Education Act of 1994," by virtue of Commission en banc Resolution No. 060-2011 dated 05 April 2011, and for the purpose of rationalizing the graduate chemistry education in the country with the end view of keeping apace with the demands of global competitiveness, the following Policies and Standards are hereby adopted and promulgated by the Commission.

ARTICLE I
INTRODUCTION

Section 1.
Graduate level study is the advanced preparation and mastery of a specialized field or discipline. It occurs within an atmosphere of intellectual and creative rigor that encourages scholarly inquiry, research and study of the evolving formulation of knowledge. Graduate education results in the candidate's ability to shape the direction of one's discipline, to become a leader in one's respective profession, and to contribute to the rapidly changing global community.

These Policies and Standards for the Masters Level of the Chemistry program seek to provide guidance in the training of master's level chemists who can work in industry, government and academe.

ARTICLE II
AUTHORITY TO OPERATE

Section 2.
All private higher education institutions (HEIs) intending to offer the degrees stated above must secure proper authority from the Commission in accordance with existing rules and regulations. State Universities and Colleges (SUCs), and Local Universities and Colleges (LUCs) should likewise strictly adhere to the provisions stated in these policies and standards.

ARTICLE III
PROGRAM SPECIFICATIONS

Section 3. Degree Names
The degree programs herein shall be called Master of Science in Chemistry (M.Sc. Chemistry) and Master of Chemistry (M. Chemistry).
Section 4. Program Description

4.1. Overview

The M.Sc. Chemistry program is thesis-based. The minimum requirement for the M.Sc. Chemistry degree is thirty-two (32) units, broken down as follows:

<table>
<thead>
<tr>
<th>Requirements for M.Sc. Chemistry</th>
<th>No. of units</th>
<th>No. of courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry Core Courses</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Electives</td>
<td>9</td>
<td>varies</td>
</tr>
<tr>
<td>Graduate Seminar</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Comprehensive Examination</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>M.Sc. Thesis (2 terms minimum)</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

**Total** 32

The M. Chemistry program is coursework-based. It may follow various tracks such as an industry, teaching, public service, etc. The minimum requirement for the M. Chemistry degree is thirty-five (35) units, broken down as follows:

<table>
<thead>
<tr>
<th>Requirements for M. Chemistry</th>
<th>No. of units</th>
<th>No. of courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry Core Courses</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Electives</td>
<td>15</td>
<td>varies</td>
</tr>
<tr>
<td>Graduate Seminar</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Comprehensive Examination</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Master’s Project</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

**Total** 35

4.2. Objectives of the Program

The M.Sc. Chemistry program aims to train chemists for careers in academe and research. The M. Chemistry program is designed to equip students with specialized training applicable to a career in chemistry and related fields or public service.

Section 5. Allied Fields

The following fields are recognized to have specializations in chemistry and their experts may be considered to teach in the Master’s program in Chemistry such as: marine science, geological sciences, physics, molecular biology and biotechnology, materials science, pharmaceutical science, food science, agricultural sciences, chemical engineering, forensic sciences and environmental science, among others.
ARTICLE IV
COMPETENCY STANDARDS

Section 6. Competency Standards
The graduate of a Master’s Degree Program in Chemistry is expected to possess a range of advanced abilities and skills that is founded upon and extends that of the Bachelor’s level in Chemistry. These are divided into three broad categories:

6.1. Chemistry-Related Cognitive Abilities and Skills
6.1.1. Ability to apply their knowledge and understanding, and problem solving abilities, in new or unfamiliar environments within broader (or multidisciplinary) context related to chemical sciences; and

6.1.2. Ability to integrate knowledge and handle complexity, and formulate judgments with incomplete or limited information, but that includes reflecting on ethical responsibilities linked to the application of their knowledge and judgments.

6.2. Chemistry-Related Practical Skills
6.2.1. Skills required for the conduct of advanced laboratory procedures and use of instrumentation in synthetic and analytical work;

6.2.2. Ability to plan and carry out experiments independently and be self critical in the evaluation of experimental procedures and outcomes; and

6.2.3. Ability to use an understanding of the limits of accuracy of experimental data to inform the planning of future work.

6.3. Generic Skills
6.3.1. Ability to communicate conclusions and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.

6.3.2. Learning skills that will allow them to continue to study in a manner that may be largely self-directed or autonomous, and to take responsibility for their own professional development.
ARTICLE V
CURRICULUM

Section 7. Student Program of Study

The Program of Study is the personal curriculum of the graduate student. After evaluation of a student applicant's background and his/her desired field of concentration, the adviser shall prepare a Program of Study for the student to be approved by the Chemistry Graduate Committee (CGC). The Program of Study will list the courses that the student will take and their sequence so that the student can complete his studies within the appropriate time frame, excluding any undergraduate or bridging courses. The HEI and the student shall be committed to fulfill the Program of Study. It is the institution's responsibility to see to it that the student completes the program of study on time and that the program maintains the expected academic standard.

Section 8. Curriculum Requirements

8.1. Chemistry Core Courses

The Chemistry Core Courses are graduate courses in five (5) areas: Inorganic Chemistry, Organic Chemistry, Analytical Chemistry, Physical Chemistry, and Biochemistry. The number of units for each course is three (3) units. The institution, however, may stipulate courses with more units, in particular if these courses have an accompanying laboratory component. The course descriptions for the core courses are given in Table 1 of Annex A.

8.2. Electives

Electives should be graduate level courses that enhance the knowledge of the student in his/her area of specialization. The electives may range from one (1) to three (3) units. The student must satisfy the total unit requirements. The electives may be varied according to the specific areas of specialization. A list of elective courses that can be offered is presented in Table 2 of Annex A.

8.3. Graduate Seminars

The objectives of the graduate seminars are: 1) to train the student to carry out extensive literature search, 2) to expose the student to various areas of Chemistry, and 3) to train them in the oral delivery of a technical paper.

8.4. Comprehensive Examination

The comprehensive examination aims to assess the student's grasp of the basic principles in chemistry and his/her ability to integrate and apply this knowledge. The comprehensive examination may be oral or written and should be taken after completing all the core courses.

8.5. Master's Project

The M. Chemistry project is an individual work wherein the student applies his/her knowledge in solving a special problem. It need not be experimental, although the project may include some laboratory experimentation. It shall be carried out under the supervision of an adviser who shall be responsible for guiding the student. The HEI and the adviser should monitor the progress of the student so that the student can finish the M. Chemistry project within the allocated time.

8.6. Thesis

The M.Sc. thesis aims to impart to the student a research experience wherein he/she becomes familiar with: research literature; methodology and skills in chemical research; effective scientific communication; and ethics of research. There are three stages: M.Sc. thesis proposal, directed research, and defense of the M.Sc. thesis. The six (6) units for the M.Sc. thesis shall be awarded after the successful defense of the thesis.
The M.Sc. thesis shall be carried out under the supervision of an adviser who shall be responsible for guiding the student in the research work. The thesis adviser should at least be a M.Sc. degree holder in chemistry. The HEI and the adviser have the responsibility to provide the necessary support so that the student can finish the M.Sc. thesis within the allocated time.

8.6.1. Thesis Proposal

Students in the M.Sc. Chemistry program are required to write a research proposal for their thesis topic and have this approved by a Thesis Committee composed of at least three (3) members one of whom is an expert from outside the department in the field of the thesis. The members of the committee shall be appointed by the CGC. Formal enrolment in the thesis should be after passing all the comprehensive examinations.

The Thesis Committee shall see to it that the thesis is of the appropriate level, is doable within the specified time period, and that the HEI can support the thesis requirements.

8.6.2. Directed Research

Directed research is a supervised laboratory course. During the period of directed research, the student conducts the investigation/study under the supervision of a thesis adviser. The institution should make available its facilities and laboratory consumables and may charge the student appropriate fees each term.

8.6.3. Defense of the Thesis

The student shall defend his/her M.Sc. thesis before the Thesis Committee appointed by the CGC. The Committee shall determine if the student has demonstrated the ability to conduct independent and meaningful research. All the members of the Committee should have at least a M.Sc. degree in Chemistry or in a field relevant to the thesis, and the chair of the Committee should have a Ph.D. in Chemistry.

SECTION 9. Methods of Teaching and Learning

A wide variety of learning and teaching approaches is to be recommended. The element of research should be considerable. Institutions are advised to consider the introduction of mentor systems as a standard feature of the Master program.

For thesis advising at the graduate level, the number of student advisees should be considered appropriate to the workload of the faculty concerned.
ARTICLE VI
LEARNING RESOURCES AND SUPPORT

PROGRAM ADMINISTRATION

The HEI is ultimately responsible for providing the faculty, library, equipment and facilities necessary for the Chemistry graduate programs.

Section 10. Chemistry Graduate Committee
The Higher Education Institution (HEI) shall create a Chemistry Graduate Committee (CGC) composed of faculty members teaching in the master’s program in chemistry. The CGC will perform the following functions:
1. Formulate policies and guidelines for the proper implementation of the program;
2. Oversee the implementation of the program; and
3. Review and monitor the program regularly.

Section 11. Faculty

11.1. Qualifications
Institutions offering the Master’s Degree Program in Chemistry must have qualified faculty, the majority of whom should be actively engaged in both teaching and research.
11.1.1. The department should have at least three (3) faculty members with Ph.D. in chemistry who will teach in the Master’s program. Two (2) of them must have full-time status.
11.1.2. To develop a critical mass of expert faculty in chemistry, the department is encouraged to have at least five (5) faculty members with Ph.D. in Chemistry, preferably one (1) specialist in each of the major field.
11.1.3. The minimum qualification for a faculty member teaching in the Master’s program shall be a M.Sc. degree in chemistry or in the allied areas.
11.1.4. The faculty is expected to be actively engaged in research and to publish in reputable refereed scientific journals.
11.1.5. The graduate faculty must be active members of recognized professional associations in chemistry.
11.1.6. The faculty is encouraged to be involved in extension activities.

11.2. Faculty Development Program
There must be provisions for the continued growth of the faculty through aid for continuous training, further studies, and travel grants to attend and/or present papers in congresses, symposia and conferences.

Section 12. Library
HEIs must meet the minimum requirements for library specified in CMO No. 18, series of 2007 (Policies and Standards for Bachelor of Science in Chemistry).

12.1. Policy
Libraries serve the instructional and research needs of the staff and students making it one of the most important service units within an HEI. It is for this reason that libraries should be given special attention by HEI administrators.
by maintaining it with a wide and up-to-date collection, qualified staff, and communications and connectivity portals.

12.2. **Library Holdings**

Library holdings should conform with existing requirements for libraries. The HEI is likewise encouraged to maintain periodicals and other non-print materials relevant to chemistry to aid the faculty and students in their academic work. Electronic media may complement a library’s book collection.

Below are the specific library requirements for the Graduate Chemistry Program:

12.2.1. It should have at least five (5) titles of graduate level books per core Chemistry subject area (Analytical Chemistry, Biochemistry, Organic Chemistry, Inorganic Chemistry, and Physical Chemistry) which are not older than 5 years. These books should be over and above the undergraduate chemistry book collection.

12.2.2. There should at least be five (5) titles of books in the research areas of the department.

12.2.3. The library should have at least two (2) journal subscriptions of international stature, preferably in chemistry fields of the institution’s specialization, in print or on-line.

12.2.4. There should be local refereed scientific journals.

12.2.5. Electronic databases are also encouraged.

12.3. **Internet Access**

Physical space for an Internet center within the institution should be provided for the exclusive use of the graduate students.

**Section 13. Facilities and Equipment**

Institutions that offer graduate degrees in Chemistry are expected to have adequate laboratory facilities and equipment to support the basic education and research needs of their graduate students. The standards for laboratory facilities and equipment for the graduate level assume compliance with the corresponding standards for the undergraduate level. The graduate Chemistry programs require substantial experimental work. It is advisable that the institution identifies its areas of specialization and develops the facilities and equipment in these areas. Graduate students should be encouraged to conduct research in these areas.

The standards are divided into two groups:
1. Standards for Stockroom and Laboratory
2. Standards for Instrumentation

13.1. **Standards for Stockroom and Laboratories**

In general, the stockroom should be adequately provided with chemicals for general and specific use. There should be adequate supply of distilled/purified water. The stockroom should be well ventilated. It should have a hood and refrigerator exclusively for chemical use. The standards for the stockroom are the same as those for the BS Chemistry program.

The laboratory should be well ventilated, well lighted, and be provided with a reliable source of water and electricity. Each student should have a minimum personal working area of 2 m², and in addition, the research student should have adequate space for equipment, refrigerator space, and writing table separate from the laboratory bench.
Trained technicians should staff stockrooms and laboratories. Guidelines pertaining to proper storage, health hazards, fire safety, and proper chemical and waste disposal should be strictly followed.

**Table 1. List of Requirements for Stockroom**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Details/Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Distillation Unit</td>
<td>Capacity should be sufficient to supply distilled water for all chemistry laboratories.</td>
</tr>
<tr>
<td>Ion-exchange Unit</td>
<td>Optional. Used primarily for Analytical Chemistry, Biochemistry, and Physical Chemistry</td>
</tr>
<tr>
<td>Fume Hood</td>
<td>The following should have a fume hood: stockroom, organic laboratory, and analytical laboratory. Other laboratories should install a fume hood as needed by the work to be performed.</td>
</tr>
<tr>
<td>Emergency Shower</td>
<td>Each teaching laboratory should have at least one emergency shower. Large laboratories should have more than one.</td>
</tr>
<tr>
<td>Emergency Eye Wash</td>
<td>May be installed as a fixed utility or a portable plastic eyewash designed for this purpose.</td>
</tr>
<tr>
<td>Refrigerator / Freezer</td>
<td>For storage of chemicals which are temperature sensitive and for making ice. For storage of volatile or flammable chemicals, a special refrigerator designed for this purpose should be used.</td>
</tr>
</tbody>
</table>

**13.2. Standards for Instrumentation**

The HEI offering a graduate degree in chemistry is required to have adequate instrumentation for its graduate laboratory courses and research areas. It is assumed that the required instrumentation for an undergraduate chemistry program has been met. Table 2 serves as a guide for the minimum expected instrumentation for the Master’s programs in chemistry:

**Table 2. List of Required Equipment**

<table>
<thead>
<tr>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzer, voltammetric</td>
</tr>
<tr>
<td>Chromatograph, gas</td>
</tr>
<tr>
<td>Chromatograph, high performance liquid</td>
</tr>
<tr>
<td>Electrophoresis</td>
</tr>
<tr>
<td>Microcentrifuge</td>
</tr>
<tr>
<td>Polarimeter</td>
</tr>
<tr>
<td>Polymerase Chain Reaction apparatus</td>
</tr>
<tr>
<td>Refractometer</td>
</tr>
<tr>
<td>Rotary evaporator</td>
</tr>
<tr>
<td>Shaker, temperature-controlled water bath</td>
</tr>
<tr>
<td>Fluorimeter</td>
</tr>
<tr>
<td>Spectrophotometer, ultraviolet visible</td>
</tr>
<tr>
<td>Spectrophotometer, atomic absorption</td>
</tr>
<tr>
<td>Spectrophotometer, Fourier transform infrared (with gas cell)</td>
</tr>
</tbody>
</table>
The department should have an equipment maintenance plan with a person in the staff who can do basic troubleshooting.

ETHICS AND RESEARCH STANDARDS

Section 14. Ethical Standards
Ethics and research standards should be a prime concern for HEIs offering graduate and undergraduate programs in chemistry. HEIs should at all times adhere to ethical standards and practice honesty in research.

14.1. Ethics in Research
Institutions must ensure the integration of concepts and practices on the ethical and responsible conduct of research. Promotion of research integrity and safe working environment reflects the commitment of the institution in research.

Academic institutions are encouraged to set the guidelines and procedures in the responsible conduct of research.

14.2. Intellectual Property
The Commission recognizes the importance of institutionalizing joint efforts and programs on the proper dissemination of information concerning the protection, development and technology transfer of intellectual creations generated by HEIs that could potentially propel the country towards national development. Hence, academic institutions should have an existing policy on intellectual property.

ADMISSION AND RETENTION REQUIREMENTS

Section 15. Admission and Retention
The Chemistry Graduate Committee (CGC) shall formulate admission requirements consistent with the objectives of the M.Sc. Chemistry and M. Chemistry programs. The applicant is expected to have either a B.S. Chemistry degree or other undergraduate degree provided that he/she has the following minimum requirements:

<table>
<thead>
<tr>
<th>Course/s</th>
<th>Units</th>
<th>Course/s</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Chemistry lecture and laboratory</td>
<td>10</td>
<td>Inorganic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>Organic Chemistry lecture and laboratory</td>
<td>5</td>
<td>Differential and Integral Calculus</td>
<td>5</td>
</tr>
<tr>
<td>Biochemistry or equivalent course</td>
<td>3</td>
<td>General Physics</td>
<td>5</td>
</tr>
<tr>
<td>Physical Chemistry lecture and laboratory</td>
<td>5</td>
<td>Undergraduate science or engineering thesis / project</td>
<td></td>
</tr>
<tr>
<td>Analytical Chemistry lecture and laboratory</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The CGC shall administer Admission Examinations covering all subjects of Chemistry for each applicant to determine the adequacy of his/her background. The CGC, upon review of the applicant's academic record and examination performance, may require that the applicant take additional undergraduate or bridging courses to compensate for any academic deficiency. These courses shall not carry any graduate course credit.
The HEI, through the CGC, shall set the standards for the grade requirement for the student to stay in the graduate program.

Section 16. Rules on Residency
The minimum residency period for the Masters Degree Programs in Chemistry is one (1) year. The maximum residency shall be five (5) years. Extension shall follow institutional policies.

Section 17. Monitoring of Masters Degree Programs in Chemistry
The CHED may, at any time, review the Masters Degree Programs in Chemistry. For this purpose, the HEI should keep a complete faculty and student file. For faculty, this shall include their faculty load, teaching, research and outreach activities, evaluation, and other relevant information. For students, this shall include courses, theses, projects, examinations and other relevant information.

ARTICLE VII
TRANSITORY, REPEALING AND EFFECTIVITY PROVISIONS

Section 18. Transitory Provision
HEIs that have been granted permit or recognition for the Masters degree in Chemistry program are required to fully comply with all the requirements in this CMO, within a non-extendable period of three (3) years after the date of its effectivity. State Universities and Colleges (SUCs) and Local Colleges and Universities (LCUs) shall also comply with the requirements herein set forth.

Section 19. Repealing Clause
All CHED issuances, rules and regulations or parts thereof, which are inconsistent with the provisions of this CMO, are hereby repealed.

Section 20. Effectivity Clause
This CMO shall take effect fifteen (15) days after its publication in the Official Gazette, or in two (2) newspapers of national circulation. This CMO shall be implemented beginning Academic Year 2012-2013.

Quezon City, Philippines, May 12, 2011.

For the Commission,

PATRICIA B. LICUANAN, Ph.D.
Chairperson

Annex A – Recommended Course Specifications
ANNEX A
RECOMMENDED COURSE SPECIFICATIONS

There are five Chemistry graduate core courses: Advanced Analytical Chemistry, Advanced Organic Chemistry, Advanced Inorganic Chemistry, Advanced Biochemistry, and Advanced Physical Chemistry. All graduate students are required to take all of these five core courses. These courses may be offered in any sequence.

The end of this section gives a list of graduate chemistry courses, including electives.

ADVANCED INORGANIC CHEMISTRY

Course description:
This course builds on the basic concepts of structure and property relationships covered in earlier inorganic chemistry courses. Structure, bonding, stereochemistry and properties of inorganic compounds will be discussed using current bonding models. This course aims to relate re-activities of inorganic compounds with their structures.

Course Credit: 3 units

Course Prerequisites:
1. A semester of undergraduate inorganic chemistry course
2. One semester of undergraduate physical chemistry course(s) that covers basic concepts in quantum chemistry
3. A semester of analytical instrumentation course

Course Outline:
1. Introduction: Atomic and Molecular Properties
2. Molecular Structure and Analytical Methods
3. Symmetry and Group Theory
   3.1. Symmetry operations
   3.2. Point groups
4. The Bonding Theories
   4.1. Valence Bond Theory
   4.2. Molecular Orbital Theory
5. Electronic States
   5.1. Electronic structures of many electron systems
   5.2. Spin-orbit coupling in free ions
   5.3. Crystal field splitting in Oh and Td complexes
6. Spectra of Metal Complexes
   6.1. Selection rules
   6.2. Electronic transitions in metal complexes
   6.3. Jahn-Teller effects
   6.4. Charge-transfer bands
7. Special Topics (optional but interesting)
   7.1. Magnetic Behavior of Inorganic Compounds
   7.2. Oxidation-Reduction Reactions
   7.3. Introduction to Organometallic Chemistry
   7.4. Introduction to Materials Science

Suggested References:
Latest editions of the following:
8. Meissler and Tarr. *Inorganic Chemistry*

And various journals and monographs in inorganic chemistry, e.g.:

*Inorganic Chemistry*

*Progress in Inorganic Chemistry*

*Organometallics*

*Journal of the American Chemical Society*
ADVANCED ORGANIC CHEMISTRY

Course Description:
This course gives a more detailed treatment of the basic principles of organic chemistry. Important concepts in the study of organic reaction mechanisms are also covered to prepare students in understanding the succeeding reactions. Topics such as pericyclic reactions and their mechanisms, reactions that involve carbanions, carbocations, free radicals, carbenes and nitrenes are intensively discussed.

Course Credit: 3 units

Course Prerequisites:

Course Outline:
1. Basic Principles of Organic Chemistry
   1.1. Chemical Bonding
       1.1.1. Localized Chemical Bonding - the covalent bond, hybridization, electronegativity, dipole moment, inductive and field effects, bond distances, bond angles, and bond energies.
       1.1.2. Delocalized Chemical Bonding - resonance effect, aromaticity, hyperconjugation and tautomerism.
       1.1.3. MO and Valence bonds - description of bonding
       1.1.4. Hückel Molecular Orbitals
   1.2. Stereochemistry
       1.2.1. Diastereomers and Enantiomers
       1.2.2. cis-trans and Z-E isomerism
       1.2.3. Optical activity and chirality
       1.2.4. Absolute configuration

2. General Consideration for Organic Reaction Mechanisms
   2.1. Thermodynamic Requirements
   2.2. Kinetic Requirements
   2.3. Basic Mechanistic Concept
       2.3.1. Kinetic vs Thermodynamic Control
       2.3.2. Hammond’s Postulate
       2.3.3. Curtin-Hammet Principle
   2.4. Methods of Determining Mechanism
       2.4.1. Identification of Products
       2.4.2. Determination of Presence of Intermediate
       2.4.3. Isotopic Labeling
       2.4.4. Isotopic Effect
       2.4.5. Stereochemical Evidence
       2.4.6. Kinetic Evidence

3. Electrophillic Reactions on Aromatic Compounds

4. Pericyclic Reaction
   4.1. Molecular Orbitals of Conjugated Polyenes
   4.2. Cycloaddition Reactions
   4.3. Electrocyclic Reactions
   4.4. Sigmatropic Reactions
5. Carbanions and Other Nucleophilic Carbon Species
   5.1. Acidity of Hydrocarbons
   5.2. Stability of Carbanion
   5.3. Enols and Enamines
   5.4. Carbanion as Nucleophiles with Carbonyl Groups

6. Reaction of Carbon Nucleophiles with Carbonyl Groups
   6.1. Aldol Condensation and Related Reactions
   6.2. Condensation Reactions of Imines and Iminium Ions
   6.3. The Wittig and Related Reactions

7. Reactions Involving Highly Reactive Electron Deficient Intermediates
   7.1. Reactions Involving Carbocations
   7.2. Reactions Involving Carbenes and Nitrenes
   7.3. Reactions Involving Free Radicals

Suggested References:
ADVANCED ANALYTICAL CHEMISTRY

Course Description:
The course presents a survey of practices and techniques in chemical analysis, particularly the instrumental methods. It will cover the fundamental principles, applications and limitations of the various methods. It will focus on how the methods have been used to solve analytical problems and will discuss the choice and efficient use of the instruments for specific chemical analysis. It will also include the application of statistical methods for the evaluation of analytical data, as well as the principles and methods of quality assurance as applied to the analytical chemistry laboratory.

Course Credit: 3 units (lecture only or lecture-laboratory combination)

Course Prerequisites:

Learning Outcome:
At the end of the course, the students shall be able to:

1. discuss the working principle of the different instrumental methods of chemical analysis, their applications and limitations;
2. apply the suitable methods to solve analytical problems;
3. apply statistical methods for the evaluation of analytical results; and
4. discuss the principles and methods of quality assurance as applied to the analytical chemistry laboratory.

Lecture:

Course Outline
1. Introduction

2. Statistical Evaluation of Data

3. Principles of Quality Assurance

4. Optical Methods

5. Electro-Chemical Methods

6. Chromatographic Methods

7. Surface Analysis and Thermal Methods
Laboratory

Suggested Experiments:

1. Spectroscopy
   1.1. Differential spectrophotometry
   1.2. Determination of the composition of complexes: mole-ratio method, continuous variation method, slope-ratio method
   1.3. Simultaneous determination of binary mixtures
   1.4. Atomic absorption spectroscopy: factors affecting absorption signal, quantitative analysis of calcium or copper
   1.5. Infrared spectroscopy: sample preparation, determination of the IR spectra of organic compounds

2. Electroanalytical Methods
   2.1. Potentiometric analysis using ion-selective electrodes
   2.2. Redox potentiometric titration
   2.3. Cyclic voltammetry and different voltammetric methods
   2.4. Heavy metal analysis by anodic stripping voltammetry

3. Chromatographic Methods
   3.1. Gas chromatography
   3.2. High performance liquid chromatography

Suggested References:

Textbooks


Monographs

Specific books on each instrumental technique

Journal papers

Selected papers from Analytical Chemistry, Analytica Chimica Acta, Analyst, Talanta.
ADVANCED PHYSICAL CHEMISTRY

Course Description:
This course shall review fundamental concepts of physical chemistry and discuss applications of these concepts to the theoretical interpretation of real data, such as experimental data from the scientific literature. The course shall cover computational techniques in physical chemistry, calculations of thermodynamic parameters such as enthalpy, entropy, and Gibbs free energy, Boltzmann energy distribution, design of kinetics experiments, a review of rudimentary quantum chemistry and spectroscopy.

Course Credit: 3 units (lecture only or lecture-laboratory combination)

Course Prerequisites: Two semesters of undergraduate physical chemistry covering thermodynamics, kinetics and basic quantum chemistry; A semester of physical chemistry laboratory; Mathematical analysis (differential and integral calculus)

Course Outline:
1. Review of Quantum Chemistry
2. Approximation Methods
3. Spectroscopy
4. Statistical Thermodynamics
5. Solid State

Suggested References:
10. Computational Software: MathCAD™, MATLAB™, or Mathematica™ ACD ChemSketch or other computer modeling software
ADVANCED BIOCHEMISTRY

Course Description:
This course covers contemporary topics of particular importance in the field of biochemistry and molecular biology. Specific topics include protein chemistry, protein folding and its three-dimensional structure and functional diversity, and methods for conformational analysis. This course will also include an overview of the chemistry of glycoconjugates and biomembranes.

This course will also cover the basic processes that govern pathways of information flow such as replication, transcription, gene expression, regulation, mutagenesis and repair.

Course Credit:                 3 units
Course Prerequisites:          10 units of Organic Chemistry and
                                3 units of Basic Biochemistry

Course Outline:
1. Molecular Architecture and Functional Diversity of Biomolecules
   1.1. Proteins and peptides
   1.2. Glycoconjugates
   1.3. Biomembranes
2. Flow of biological Information
   2.1. Structural properties of DNA
   2.2. DNA replication, repair and recombination
   2.3. Structural properties of RNA
   2.4. RNA synthesis and processing
   2.5. Transcription
   2.6. Protein synthesis, targeting and turnover
   2.7. Signal transduction
   2.8. Mutagenesis and repair
   2.9. Recombinant DNA technology

Suggested References:
LIST OF GRADUATE CHEMISTRY COURSES

Graduate chemistry courses should be at the advanced level and reflect the current state of the field. Therefore, the topics and reading materials should be both advanced and up-to-date. The use of journal articles, especially important recent ones, is encouraged.

Table 1 lists some courses that may be offered in the master’s programs. Units for the required courses are indicated. Number of units for Chemistry Electives may range from one (1) to three (3) units, depending on course coverage. This table is not meant to be comprehensive. Institutions are encouraged to develop their own courses.

Table 1. List of Graduate Chemistry Courses

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Core Subjects</strong></td>
<td></td>
</tr>
<tr>
<td>Advanced Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>Advanced Analytical Chemistry or Advanced Instrumentation</td>
<td>3</td>
</tr>
<tr>
<td>Advanced Inorganic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>Advanced Biochemistry</td>
<td>3</td>
</tr>
<tr>
<td>Advanced Physical Chemistry</td>
<td>3</td>
</tr>
<tr>
<td><strong>B. Chemistry Electives</strong></td>
<td></td>
</tr>
<tr>
<td>Advanced Cell and Molecular Biology</td>
<td></td>
</tr>
<tr>
<td>Advanced Environmental Chemistry</td>
<td></td>
</tr>
<tr>
<td>Advanced Geochemistry</td>
<td></td>
</tr>
<tr>
<td>Advanced Quantum Chemistry</td>
<td></td>
</tr>
<tr>
<td>Advanced Spectroscopy</td>
<td></td>
</tr>
<tr>
<td>Advanced Polymer Chemistry</td>
<td></td>
</tr>
<tr>
<td>Advanced Thermodynamics</td>
<td></td>
</tr>
<tr>
<td>Applied Analytical Science (e.g., Food analysis, Bioanalysis)</td>
<td></td>
</tr>
<tr>
<td>Atmospheric Chemistry</td>
<td></td>
</tr>
<tr>
<td>Biochemical Catalysis</td>
<td></td>
</tr>
<tr>
<td>Bioinorganic Chemistry</td>
<td></td>
</tr>
<tr>
<td>Biophysical Chemistry</td>
<td></td>
</tr>
<tr>
<td>Biotechnology and Molecular Biology</td>
<td></td>
</tr>
<tr>
<td>Carbohydrate Chemistry</td>
<td></td>
</tr>
<tr>
<td>Chemical Bonding</td>
<td></td>
</tr>
<tr>
<td>Chemical Kinetics</td>
<td></td>
</tr>
</tbody>
</table>
### Course Title

- Chemical Toxicology
- Chemistry of Fats and Lipids
- Chemistry of Nucleic Acids
- Chemometrics
- Chromatographic Methods of Analysis
- Computational Chemistry and Molecular Modeling
- Coordination Chemistry
- Electroanalytical Chemistry
- Enzyme Chemistry
- Heterocyclic Chemistry
- Industrial Chemical Processes
- Marine Chemistry
- Materials Chemistry
- Medicinal Chemistry
- Modern Instrumental Analysis
- Natural Products Chemistry
- Organic Synthesis
- Organometallic Chemistry
- Petroleum Chemistry
- Philosophy of Science
- Polymer Synthesis and Characterization
- Protein Chemistry
- Quantum Chemistry
- Special Topics in Analytical Chemistry
- Special Topics in Biochemistry
- Special Topics in Inorganic Chemistry
- Special Topics in Natural Products Chemistry
- Special Topics in Organic Chemistry
- Special Topics in Physical Chemistry
- Stereochemistry

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. Chemistry Research</strong></td>
<td></td>
</tr>
<tr>
<td>Comprehensive Examination</td>
<td>0</td>
</tr>
<tr>
<td>Master's Project</td>
<td></td>
</tr>
<tr>
<td>Preparation of MS Thesis Proposal</td>
<td>0</td>
</tr>
<tr>
<td>Directed research (MS thesis)</td>
<td>0</td>
</tr>
<tr>
<td>Defense of MS Thesis</td>
<td>6</td>
</tr>
<tr>
<td>Course Title</td>
<td>Units</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>D. Graduate Seminar</strong></td>
<td></td>
</tr>
<tr>
<td>Graduate Seminar in Inorganic Chemistry I</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Inorganic Chemistry II</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Organic Chemistry I</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Organic Chemistry II</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Analytical Chemistry I</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Analytical Chemistry II</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Physical Chemistry I</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Physical Chemistry II</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Biochemistry I</td>
<td>1</td>
</tr>
<tr>
<td>Graduate Seminar in Biochemistry II</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2 is an indicative list of elective courses that an institution can offer in training students for special areas. This is not meant to limit the courses to be taken by students, but as a guide to the preparation of the student's Program of Study.

**Table 2. Indicative List of Elective Courses for Various Fields of Specialization. This list is not meant to be comprehensive.**

<table>
<thead>
<tr>
<th>Area of Specialization</th>
<th>RECOMMENDED Elective Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical Chemistry</td>
<td>Advanced environmental chemistry, advanced spectroscopy, applied analytical science, chemometrics, chromatographic methods of analysis, electroanalytical chemistry, modern instrumental analysis, special topics in analytical chemistry</td>
</tr>
<tr>
<td>Biochemistry</td>
<td>Advanced cell and molecular biology, biochemical catalysis, bioinorganic chemistry, biophysical chemistry, biotechnology and molecular biology, chemical toxicology, chromatographic methods of analysis, computational chemistry and molecular modeling, enzyme chemistry medicinal chemistry, natural products chemistry, special topics in biochemistry</td>
</tr>
<tr>
<td></td>
<td>Advanced microbiology</td>
</tr>
<tr>
<td>Area of Specialization</td>
<td>RECOMMENDED Elective Courses</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Environmental Chemistry</td>
<td>Advanced environmental chemistry, advanced spectroscopy, applied analytical science, atmospheric chemistry, chemometrics, chromatographic methods of analysis, electroanalytical chemistry, marine chemistry, modern instrumental analysis, special topics in analytical chemistry</td>
</tr>
<tr>
<td>Food Chemistry</td>
<td>Advanced cell and molecular biology, applied analytical science, bioinorganic chemistry, biotechnology and molecular biology, chemical toxicology, chromatographic methods of analysis, computational chemistry and molecular modeling, enzyme chemistry, medicinal chemistry, natural products chemistry, special topics in biochemistry, special topics in natural products chemistry Advanced microbiology, Food Engineering</td>
</tr>
<tr>
<td>Inorganic Chemistry</td>
<td>Advanced quantum chemistry, advanced spectroscopy, advanced polymer chemistry, advanced thermodynamics, atmospheric chemistry, bioinorganic chemistry, chemical bonding, chemical kinetics, computational chemistry and molecular modeling, coordination chemistry, electroanalytical chemistry, advanced geochemistry, materials chemistry, modern instrumental analysis, organometallic chemistry, quantum chemistry, special topics in inorganic chemistry, stereochemistry</td>
</tr>
<tr>
<td>Materials Science</td>
<td>Advanced quantum chemistry, advanced spectroscopy, advanced polymer chemistry, advanced thermodynamics, chemical bonding, chemical kinetics, computational chemistry and molecular modeling, coordination chemistry, electroanalytical chemistry, materials chemistry, modern instrumental analysis, organometallic chemistry, quantum chemistry, special topics in inorganic chemistry, stereochemistry</td>
</tr>
<tr>
<td>Area of Specialization</td>
<td>RECOMMENDED Elective Courses</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Natural Products Chemistry</td>
<td>Applied analytical science, biochemical catalysis, biotechnology and molecular biology, chemical toxicology, chromatographic methods of analysis, computational chemistry and molecular modeling, enzyme chemistry, heterocyclic chemistry, marine chemistry, medicinal chemistry, modern instrumental analysis, natural products chemistry, organic synthesis, special topics in natural products chemistry, stereochemistry, Microbiology, Botany</td>
</tr>
<tr>
<td>Organometallic Chemistry</td>
<td>Advanced quantum chemistry, advanced spectroscopy, advanced thermodynamics, bioinorganic chemistry, chemical bonding, chemical kinetics, computational chemistry and molecular modeling, coordination chemistry, electroanalytical chemistry, materials chemistry, modern instrumental analysis, organometallic chemistry, quantum chemistry, special topics in inorganic chemistry, stereochemistry</td>
</tr>
<tr>
<td>Organic Synthesis</td>
<td>Applied analytical science, biochemical catalysis, chromatographic methods of analysis, computational chemistry and molecular modeling, enzyme chemistry, heterocyclic chemistry, medicinal chemistry, modern instrumental analysis, natural products chemistry, organic synthesis, special topics in natural products chemistry, special topics in organic chemistry, stereochemistry, Microbiology</td>
</tr>
<tr>
<td>Physical Organic Chemistry</td>
<td>Advanced spectroscopy, advanced quantum chemistry, atmospheric chemistry, biophysical chemistry, chemical bonding, chemical kinetics, chemometrics, chromatographic methods of analysis, electroanalytical chemistry, enzyme chemistry, modern instrumental analysis, quantum chemistry, special topics in analytical chemistry, special topics in physical chemistry, stereochemistry</td>
</tr>
<tr>
<td>Area of Specialization</td>
<td>RECOMMENDED Elective Courses</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Polymer Chemistry</td>
<td>Applied analytical science, chromatographic methods of analysis, computational chemistry and molecular modeling, materials science, modern instrumental analysis, organic synthesis, polymer synthesis and characterization, special topics in organic chemistry, stereochemistry Materials Engineering</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>Advanced spectroscopy, advanced quantum chemistry, advanced spectroscopy, applied analytical science, chemometrics, chromatographic methods of analysis, electroanalytical chemistry, modern instrumental analysis, quantum chemistry, special topics in analytical chemistry, stereochemistry</td>
</tr>
</tbody>
</table>