# INTRODUCTION
# OF
# SCIENCE RESEARCH TRAINING
# INTO THE CURRICULUM

Sabbatical Project Report

Fall 2006 – Spring 2007

Jenny S. Chen

Chemistry Department

# Table of Contents

# Acknowledgments

I would like to acknowledge the invaluable support that many people have provided during the course of my sabbatical leave from Mt. San Antonio College. First and foremost, I am enormously grateful to the college administration and leadership, as well as the Salary and Leaves Committee for granting me this wonderful opportunity to work on the project. On both professional and personal levels, it is very exciting for me to see that the idea of introducing science research training into the curriculum at Mt. SAC is well received and supported. I deeply appreciate working at an institution that is strongly committed to educational excellence and fully supports faculty development.

I am also grateful for the continuous support from both the Natural Science Division and the Chemistry Department. I wish to express my sincere appreciation to Larry Redinger (Dean of Natural Sciences Division) and Debbie Boroch (Associate Dean of Natural Sciences Division) for their unwavering support and exemplary leadership throughout the years. To all of my colleagues in the Chemistry Department, I am thankful for their support for my sabbatical project and their shared commitment to providing quality education to our students.

# Statement of Purpose

The purpose of this sabbatical project is to research, design, and initiate the establishment of two research training courses – "Introduction to Science Research" and "Science Research Methodologies and Instrumentation" – in the Chemistry Department at Mt. San Antonio College. The eventual goal of these courses is to serve as gateway courses to effectively prepare students for research projects on campus, summer research at other institutions, research at their transfer institutions, and future careers in science. Ultimately, these courses will provide the rare opportunity for students to think and work like a scientist, improve problem-solving skills, develop professional communication skills, enhance teamwork skills, increase self-confidence as an independent learner/researcher, and gain proficiency in the use of scientific instrumentation.

To accomplish this goal, the first imperative step of the sabbatical project is to conduct a comprehensive research and investigation process on similar types of courses offered at other institutions. This comprehensive search consists of three main components, each with a specific objective:

- Search the catalogs of all California universities and four-year colleges for research training or research-related course offerings and examine their course content. Since most Mt. SAC students transfer to institutions within California, the objective of this search is to provide valuable insights on what the students should be prepared for upon transferring and to create a course that is most beneficial to our students.
- Search the major federal funding agencies websites for past grant awards that support research training or research-related programs. The objective of this

search is to locate federal-funded undergraduate research opportunities that Mt. SAC students can participate in.

- Search relevant journals for research training, research-related courses and implementation of research into the curriculum. The objective of this search is to identify successful practices on a national level that enable faculty (and institutions) to design, implement, and sustain a research-supportive curriculum.

Once the comprehensive research and investigation phase is completed, the compiled data are summarized and analyzed.

The second important step of the sabbatical project is to design the two courses based on the results from the comprehensive search. Results are utilized to evaluate, assess and determine the essential components for the two courses, using the initial outlined topics (in the sabbatical project proposal) as the template. Course goals, objectives, topics, methods of evaluation and assessment are established.

The last crucial step of the sabbatical project is to create and develop course materials according to the selected topics. The approach utilized here is to adopt and adapt appropriate case studies, inquiry-based experiments, and discovery-based projects that have been published or cited in literature as successful practices. Specifically, key selection criteria include relevancy to the courses' objectives and topics, ability to stimulate student interest, and capability to provide hands-on training of instruments. In addition, both courses should offer valuable opportunities for students to share their work with their peers in a professional manner via oral and written scientific presentations.

In any academic endeavor, the fundamental purpose is to provide quality education to the students, and this sabbatical project is no exception. Since undergraduate research plays a pivotal role in science students' success to graduation and their choice to pursue careers in sciences, the development of these two research training courses serves to effectively provide such invaluable, exceptional learning experiences to the general student population at Mt. SAC.

# Project Activities

*Part 1: Research and Investigation on Research Training Courses*

## Research Approach and Methodology

To design research training courses that are most beneficial for Mt. SAC students, it is imperative to first conduct a comprehensive search and investigation on the similar type of courses offered at four-year institutions. Specifically, the focus is on the most popular universities and colleges that Mt. SAC students transfer to, so that the students will be properly prepared to participate in undergraduate research upon transferring to these institutions. According to Mt. SAC's Career and Transfer Services, the most popular schools that students transfer to include UCLA, UC Irvine, UC Riverside, UC Berkeley, Cal Poly Pomona, CSU Fullerton, CSU Los Angeles, CSU San Bernardino, University of Phoenix, Azusa Pacific University, DeVry University, USC, and Chapman University. Since all of these institutions are located in California, therefore, a thorough search of the catalogs for all California universities and colleges becomes the first step in this research phase of the sabbatical project. Specifically, this search includes the 10 University of California (UC) campuses, 23 California State University (CSU) campuses, and other private/independent universities and colleges in California. The search concentrates on any type of undergraduate research training or research-related courses in Chemistry and their course content. With the availability of information online, most of this research is conducted via the institutions' websites.

The second step in the research and investigation process involves searching for any type of undergraduate research training or research-related courses/programs in Chemistry on a national level. After much consideration, it is determined that simply searching the catalogs of every four-year institutions that offered Chemistry degrees is not only extremely time consuming, but highly inefficient in identifying the successful cases of science research implementation into the curriculum. Instead, the approach utilized for this sabbatical project is to search the websites of major federal funding agencies to investigate which institutions have received funding in recent years to create research-related programs, especially ones that provide opportunities for undergraduate research for community college students. The targeted funding agencies include National Science Foundation and National Institute of Health, since these are the primary funding agencies for promoting and advancing science education and research in United States. Both of these agencies offer various types of funding in different categories; therefore, a thorough search for past awards in relevant categories is conducted.

In addition, the research process also focuses on relevant journals such as Journal of Chemical Education as well as publications from Council on Undergraduate Research and Chemical & Engineering News. Again, the objective here is to seek out successful practices on a national level in an effective and efficient manner, with specific focus on research-related course, programs and curricula. Since Journal of Chemical Education serves as the main platform for communicating educational innovations in chemical sciences, the research and investigation process for this journal involves both utilizing the online search engine for all the issues as well as meticulously examining all the articles in issues from years 2000 – 2007 for relevant publications and useful references.

To complete the research and investigation phase, attendances at two conferences, one national (Council on Undergraduate Research's 2006 National Conference – Learning Through Research: Dynamic Faculty, Students, and Institutions) and one local

(Council on Undergraduate Research's 2007 Regional Workshop Program on Institutionalizing Undergraduate Research), are served as opportunities to dialogue with specific faculty from various institutions that offer research training courses or have implemented research components into the curriculum. The objective here is to learn about successful practices to adopt, challenges to overcome, and pitfalls to avoid.

The overall goal in these research and investigation efforts is to obtain a comprehensive understanding on the current status of Chemistry research training in California universities and colleges, types of research programs available to Mt. SAC students, as well as the existing progress of successfully implemented research-related curricular practices on a national level. The collected data and analyzed findings from this research process are summarized in the next three sections of the report. These three summaries also identify patterns of similarities and differences, as well as key components in the various courses or programs. Ultimately, the analyzed results will then be utilized to evaluate and determine the essential components for the two proposed courses in the sabbatical project (using the outlined topics in the sabbatical proposal as the template); the design of the two proposed courses will be described in detail in Parts 2 and 3 of this report.

## Summary on Courses Offered by California Universities/Colleges

The results of searching the catalogs for all California universities and colleges for any type of undergraduate research training or research-related courses in Chemistry and their course content are summarized here in three sections – UC campuses, CSU campuses and private/independent institutions.

### UC Campuses

Research shows that all ten UC campuses do not offer any formal research training course in Chemistry. However, nine of the ten UC campuses offer some type of undergraduate research-related course in Chemistry. The remaining UC campus, UC San Francisco, which does not offer undergraduate degree programs, is not included in this discussion. The following table summarizes the details of these undergraduate research-related courses in Chemistry for the nine UC campuses, with the four most transferred destinations for Mt. SAC students listed first.

**Table 1. Summary of undergraduate research-related courses in UC schools.**

| School | Course number | Course Title | Course Description | Number of Units | Prerequisites |
|---|---|---|---|---|---|
| **UC Berkeley** | C96 | Introduction to Research and Study in the College of Chemistry | One hour of seminar per week. Introduces freshmen to research activities and programs of study in the College of Chemistry. Includes lectures by faculty, an introduction to college library and computer facilities, the opportunity to meet alumni and advanced undergraduates in an informal atmosphere, and discussion of college and campus resources. Must be taken on a passed/not passed basis.<br><br>**Lower division course.* | 1 | Freshman standing in chemistry or chemical engineering major or consent of instructor. |
| | H194 | Research for Advanced Undergraduates | Course may be repeated for credit. Minimum of three hours of work per week per unit of credit. Students may pursue original research under the direction of one of the members of the staff. | 2-4 | Minimum GPA of 3.4 overall at Berkeley and consent of instructor and adviser. |
| **UCLA** | 196A | Research Apprenticeship in Chemistry and Biochemistry | Tutorial, three hours per week per unit. Limited to juniors/seniors. Entry-level research apprenticeship for upper division students under guidance of faculty mentor. Consult department for additional information regarding requirements, enrollment petitions, and written proposal deadlines. May be repeated for a | 2-4 | Junior standing with a 3.0 GPA in the major **OR** senior standing **OR** consent of the instructor and department chair.<br><br>Note: To enroll, students must completely fill out the |

| | | | | | |
|---|---|---|---|---|---|
| | | | maximum of 8 units. Individual contract required. P/NP grading.<br><br>*Take during the 1st and 2nd research quarters. | | proper petition form and write a proposal outlining the research project. The petition and proposal **MUST** be evaluated and approved **BEFORE** enrollment is granted. |
| | 196B | Research Apprenticeship in Chemistry and Biochemistry | Tutorial, three hours per week per unit. Limited to juniors/seniors. Research apprenticeship for upper division students under guidance of faculty mentor. Consult department for additional information regarding requirements, enrollment petitions, and written proposal deadlines. May be taken for a maximum of 4 units. Individual contract required. P/NP or letter grading.<br><br>*Take during the 3rd research quarter. | 2-4 | Chem 196A (8 units) |
| | 199 | Directed Research in Chemistry and Biochemistry | Tutorial, three hours per week per unit. Limited to juniors/seniors. Supervised individual research under guidance of faculty mentor. Culminating report required. May be repeated for a maximum of 12 units. Individual contract required. P/NP or letter grading.<br><br>*Take during final research quarters. | 2-4 | Chem 196B (4 units) |

| | | | | | |
|---|---|---|---|---|---|
| **UC Irvine** | 180 | Undergraduate Research | The student wishing to engage in research for credit should arrange with a member of the faculty to sponsor and supervise such work. A student time commitment of 10 to 15 hours per week is expected, and a written research report is required at the end of each quarter of enrollment. | 4 | Consent of a faculty sponsor. |
| | H180A<br>H180B<br>H180C | Honors Research in Chemistry | Undergraduate honors research in Chemistry. A student time commitment of 10-15 hours per week is required. | 4<br>4<br>4 | Consent of instructor; open to participants in the Chemistry Honors program and to Chemistry majors participating in the Campuswide Honors Program.<br><br>*Corequisite for H180C: Chemistry H181 (Honors Seminar in Chemistry). |
| **UC Riverside** | 197 | Research for Undergraduates | Outside research, 3-12 hours. An introduction to the methods of research in chemistry. Includes a research project completed under the supervision of a Chemistry faculty member. Students who submit a written research report receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable to a maximum of 6 units. | 1-4 | Sophomore or junior standing; consent of instructor.<br><br>Completion of one year of general chemistry and usually one year of organic chemistry with a good GPA ($\geq$2.0). |

| | | | | | |
|---|---|---|---|---|---|
| | 199<br><br>199H | Senior Research<br><br>Senior Honors Research | Outside research, 3-12 hours. Research project completed under the supervision of a Chemistry faculty member. Students who submit a written research report receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Total credit for CHEM 199 and/or CHEM 199H may not exceed 9 units. | 1-4 | Senior standing; consent of instructor. |
| **UC Davis** | 194HA<br>194HB<br>194HC | Undergraduate Honors Research | Independent study--2 hours. Original research under the guidance of a faculty adviser, culminating in the writing of an extensive report. (Deferred grading only, pending completion of sequence.) | 2<br>2<br>2 | Open only to chemistry majors who have completed 135 units and who qualify for the honors program. |
| **UC San Diego** | 199 | Reading and Research | Independent literature or laboratory research by arrangement with, and under the direction of, a member of the Department of Chemistry faculty. Students must register on a P/NP basis. | 2 or 4 | Upper-division standing (have completed 90 or more units), 2.5 minimum GPA, consent of instructor and department. |
| **UC Santa Barbara** | 99 | Introduction to Research | Directed study, normally experimental, to be arranged with individual faculty members. Course offers exceptional students an opportunity to participate in a research group. Basic techniques and the operation of instruments used in research. Tutorial, 3-9 hours. May be repeated to a maximum of 6 units.<br>**Lower division course.* | 1-3 | Consent of instructor. |

| | | | | | |
|---|---|---|---|---|---|
| | 199 | Independent Studies in Chemistry and Biochemistry | Coursework shall consist of academic research supervised by a faculty member. This course is not intended for internship credit. Tutorial, 1-5 hours. No more than 12 units of Chemistry 199 may apply toward the B.S. in Chemistry. | 1-5 | Upper-division standing in the major; completion of two upper-division courses in chemistry. Must have a minimum 3.0 grade-point average for the preceding three quarters. |
| **UC Santa Cruz** | 180A<br>180B<br>180C | Senior Research | An individually supervised course with emphasis on independent research. Multiple-term course extending over two or three quarters; the grade and evaluation submitted for the final quarter apply to all previous quarters. May not be repeated for credit. | *not specified | Students submit petition to sponsoring agency. |
| **UC Merced** | 95 | Undergraduate Research | Supervised research.<br><br>*Lower division course. | 1-5 | Permission of instructor required. |
| | 195 | Undergraduate Research | Supervised research. | 1-4 | Permission of instructor required. |

Analysis of the above table reveals some important trends of similarities. First, majority of these research-related courses (with the exception of three) are upper division courses, limited to students with either junior or senior standing. Second, most of these courses require instructor consent, indicating that students would have to take the first initiative to contact the professors to express interest in research and that not all students would be accepted into the course. Third, as reflected by the course descriptions, none of these upper division research courses offer any formal training to the students prior to engaging in a research project. Clearly, this implies that students with more research training preparation would have a strong advantage in succeeding in these research courses. Fourth, for five of the UC campuses, a GPA requirement is part of the prerequisite. In addition, for the four most popular transfer destinations for Mt. SAC students (UC Berkeley, UCLA, UC Irvine and UC Riverside), three of them require some type of written research report in their courses.

As part of the research on these courses and the program requirements, an important finding that relates to these courses, but not reflected in the above table, is observed. For six of the UC campuses (UC Berkeley, UC Irvine, UC Davis, UC San Diego, UC Santa Barbara, UC Santa Cruz), these research courses can count as upper division electives toward completion of major requirements. In addition, for UC Merced, five units of the research courses are required for all B.S. degrees in Chemistry, regardless of individual emphases. Also, for UC Berkeley, all incoming students that enter the College of Chemistry as freshmen are required to take the "Introduction to Research and Study" course during their first fall semester. This trend in UC institutions reflects the importance and pedagogical value of undergraduate research in education.

Based on the above observed patterns and the course requirements described in Table 1, it is determined that in order to properly prepare Mt. SAC students to participate in research upon transferring, they must be equipped with the following:

- Motivation to take initiative in contacting professors to seek out a research group to work in;
- Ability to read and understand scientific literature;
- Capability to understand the various faculty research projects to discover one's research interest;
- Exposure to or hands-on experience in high-tech instrumentations in research;
- Experience in writing scientific proposals or reports;
- Communication skills to present research results in a scientific manner; and
- Ability to work independently.

These factors help to guide the selection of course topics as well as development of course materials in the later stages of this sabbatical project.

**CSU Campuses**

Research shows that all 23 CSU campuses do not offer any formal research training course in Chemistry. However, 21 of the 23 CSU campuses offer some type of undergraduate research-related course in Chemistry. The two remaining CSU campuses (California Maritime Academy and CSU Monterey Bay), which do not offer degree programs in Chemistry, are not included in this discussion. The following table summarizes the details of these undergraduate research-related courses in Chemistry for the 21 CSU campuses, with the four most transferred destinations for Mt. SAC students listed first.

**Table 2. Summary of undergraduate research-related courses in CSU schools.**

| School | Course number | Course Title | Course Description | Number of Units | Prerequisites |
|---|---|---|---|---|---|
| **Cal Poly Pomona** | 491<br>492 | Senior Research Project | Senior level research or project. Individual consultation and supervision. Independent literature review, project design, data collection and interpretation of results. Formal report. | 3<br>3 | Minimum GPA of 2.0 in major. |
| **CSU Fullerton** | 395 | Undergraduate Research | Independent research in chemistry or biochemistry under the guidance of a department faculty member. May be repeated for credit. Does not count towards major. 3 hours per week per unit. 4 units maximum. | 1-3 | Completion of one upper-division course in chemistry, one semester of experience working in a research laboratory, and consent of instructor. |
| | 495 | Senior Research | The methods of chemical research through a research project under the supervision of one of the Department faculty. May be repeated for credit. Only 6 units may apply toward B.A. or B.S. degree. 3 hours per week per unit. | | Three one-year courses in chemistry, Chemistry 390 (Careers in Chemistry and Biochemistry), and consent of instructor.<br><br>Corequisite: Chemistry 340 (Writing for the Chemical Sciences). |
| **CSU Los Angeles** | 499 | Undergraduate Directed Study | Ability to assume responsibility for independent work and to prepare written and oral reports. Independent research project selected in conference with sponsor | 1-5 | Requires a 2.5 GPA in chemistry courses or one advanced laboratory course elective, and the consent of |

| | | | | | |
|---|---|---|---|---|---|
| | | | before registration; progress meetings held regularly. May be repeated to maximum of 9 units. | | instructor to act as sponsor. |
| | 396 | Honors Studies in Chemistry | Independent research in chemistry and biochemistry. Regular consultation with research adviser; written thesis required. Students must enroll for total of 5 units before submitting thesis and receiving grade.<br><br>Honors students must write a thesis based on their research and pass an oral examination relating to their project. Students who complete this program graduate with departmental honors. | 1-5 | Entry into this research program requires a 3.0 GPA in all college work and in chemistry, averaged separately, and recommendations from at least two faculty members.<br><br>Participation in Chemistry Honors Program, consent of an instructor to serve as research adviser, and approval of department honors adviser. |
| **CSU San Bernan-dino** | 595 | Independent Study | Laboratory and/or library research conducted under the direction of a faculty member. Final written report required. A total of six units in CHEM 595 may be applied toward the major. | 1-6 | A minimum overall grade point average of 2.5, consent of instructor and departmental approval of a written proposal of a project submitted on a standard application filed in advance of the quarter in which the course is to be taken. |

| | | | | | |
|---|---|---|---|---|---|
| **CSU Bakers-field** | 480 | Honors Research | Individual study on a current research problem with faculty supervision, preparation of a paper. Course may be repeated twice with permission of the instructor. Normally a maximum of five units may be used for major department credit. Units in excess of five may be used for upper division elective credit. | 5 | Invitation by faculty. |
| **CSU Channel Island** | 494 | Independent Research | Provides student credit for independent research (laboratory or library) that culminates in a written and oral report. Repeatable. | 1-3 | Consent of instructor. |
| **CSU Chico** | 490 | Research in Chemistry | This course is an independent study. You must register directly with a supervising faculty member. Original laboratory or library investigation under individual faculty supervision. You may take this course more than once for a maximum of 4.0 units. | 1-2 | CHEM 332 *(Physical Chemistry)*. |
| | 491 | Research Project | A research project within chemistry or an interdisciplinary project which involves chemistry. Students will be involved with design, library, laboratory, and data analysis aspects of a research problem. | 3 | Open by invitation to chemistry majors with a GPA of 3.0 or higher; faculty permission. |
| | 492 | Research Project | A continuation of CHEM 491. | 3 | CHEM 491. Faculty permission. |

| | | | | | |
|---|---|---|---|---|---|
| | 499H | Honors Research Project | This is an "Honors in the Major" course. You may take this course more than once for a maximum of 6.0 units. This is a writing proficiency, WP, course; a grade of C- or better certifies writing proficiency for majors. ABC/no credit grading only.<br><br>*Not open to students who have credit for CHEM 491 or CHEM 492. | | Open by invitation to chemistry majors who have a GPA of 3.5 or higher. Faculty permission. |
| **CSU Doming-uez Hills** | 497 | Directed Research | Advanced laboratory work, with each student undertaking an independent and original investigation. CR/NC grading. Repeatable course. Three or nine hours of laboratory per week. | 3 | Senior standing and consent of instructor. |
| **CSU East Bay** | 4810 | Undergraduate Research | Independent research under the guidance of a member of the Chemistry Department faculty. May be repeated once for credit. Students should consult with faculty members to determine specific research opportunities. | 2 | CHEM 3532 (Physical Chemistry Lab) and consent of instructor. |
| **CSU Fresno** | 190 | Independent Study | Almost all of the time is spent in the laboratory, or search for and reading chemical literature (library or online). Must submit a concise, well-written, comprehensive, and well-documented Research Report. Maximum credit of 6 units is allowed toward the bachelor's degree. | 1-3 | Overall GPA of 3.0 or higher. Obtain the consent of an instructor, who will guide the project, and the chair of the department in which the course is given. |

| | | | | | |
|---|---|---|---|---|---|
| **Humbol-dt State Universi-ty** | 495 | Undergraduate Research | Individual investigation of selected problem. Conference, reading, research. Final written report. For students showing outstanding ability. May be repeated. | 1-3 | Instructor Approval. |
| **CSU Long Beach** | 466H | Research Design and Methods – Honors | Introduction to hypothesis testing, experimental design, and regression modeling of biological data; methodological and technical procedures for experimentation; and techniques for written and oral presentation of research results. Research paper and oral presentation required. Same course as BIOL 466H. Letter grade only. Lecture 3 hours. | 3 | BIOL 211A,B (Biological Sciences), either BIOL 260 (Biostatistics) or CHEM 251 (Quantitative Analysis), CHEM 320A,B (Organic Chemistry), all with a grade of "C" or better, and completion of the GE Foundation. |
| | 496 | Special Problems in Chemistry | Problems selected for considered and mature analysis. A written report required. Also known as Undergraduate Directed Research. | 1-3 | Consent of instructor. |
| **CSU North-ridge** | 495 | Directed Undergraduate Research | A course designed for students of advanced rank and proven competence in chemistry. A program of original independent research, culminating in a written report, to be carried out under the direction of one of the Chemistry faculty. Upon prior approval by the Chemistry Department of a detailed research proposal, the research may be performed in industrial or medical laboratories. In such a case, the research | 1-3 | One course beyond CHEM 102 (General Chemistry II) in the area related to the research.<br><br>Interested students should make arrangements with the department as soon as possible, preferably during the previous semester. |

| | | | | | |
|---|---|---|---|---|---|
| | | | report must be submitted to and evaluated by a designated member of the Chemistry faculty. This course may be repeated for credit. | | |
| **CSU Sacra-mento** | 189 | Directed Research | Directed undergraduate research involving a project that requires inquiry and use of chemical literature. A well-written, comprehensive and well-documented final report must be submitted to receive a final grade. May be repeated; however only three units may be applied toward the major requirement in chemistry for the BA or BS degrees. Additionally, the final report must be based on experimental techniques or advanced computer modeling and demonstrate a significant ability to use chemical literature and information retrieval. | 1-3 | ENGL 020 or an equivalent second semester composition course and instructor and department chair permission. |
| | 198 | Senior Research | The student will conduct an independent study of a chemical research topic that is based on experimental techniques or advanced computer modeling. Significant use of chemical literature and information retrieval is required. A well-written, comprehensive, and well-documented final report must be submitted to receive a final grade. A weekly seminar is required. Seminar one hour, laboratory activities are a minimum of six hours per week. | 3 | One upper division chemistry laboratory class, ENGL 020 or an equivalent second semester composition course and instructor and department chair permission. |

| | | | | | |
|---|---|---|---|---|---|
| **San Diego State University** | 297 | Introduction to Chemical Research | Individual laboratory investigation. Maximum credit six units. Available to freshman and sophomore students who wish to start laboratory research early. Starting laboratory work early in one's undergraduate program can be the deciding factor in completing successful, professional-quality research projects. | 1-3 | Consent of instructor. |
| | 497 | Undergraduate Research | Individual laboratory investigation. Maximum credit six units. This course is intended for upper division students who wish to pursue laboratory research on a credit/no credit basis, with no required final report. This course can contribute to elective units in chemistry required by the various degree programs. | 1-3 | Chemistry 231 (Organic Chemistry) and 251 (Analytical Chemistry). |
| | 498 | Senior Project | Individual literature and/or laboratory investigation and report on a problem. Maximum credit three units. This course is required for all B.S. chemistry majors, and is open to all other students who have the prerequisite coursework and wish to receive letter-grade credit for their research. A final report is required at the conclusion of the course. | 1-3 | Three one-year courses in chemistry. |

| | | | | | |
|---|---|---|---|---|---|
| **San Francis-co State Univer-sity** | 470 | Research | Intended for motivated students interested in independent research. Requires 6-9 hours of research each week, lecture attendance, formal poster presentation, and written report. May be repeated for a total of 6 units. | 3 | One year each of general and organic chemistry and consent of instructor and faculty research advisor. |
| **San Jose State Univer-sity** | 180 | Individual Studies | Advanced supervised lab work. Work and results described in written and oral reports as required by instructor. An honors course. Repeatable for credit | 1-4 | CHEM 120S (Chemical Safety Seminar), instructor consent and "B" average. |
| **Cal Poly San Luis Obispo** | 201 | Undergraduate Research | Laboratory research under faculty supervision. Credit/No Credit grading only. Total credit limited to 6 units. | 1-3 | Consent of instructor. |
| | 401 | Advanced Undergraduate Research | Laboratory research under faculty supervision. Credit/No Credit grading only. Total credit limited to 6 units. 4 units may be applied to approved chemistry electives. | 1-3 | Consent of instructor. |
| | 463 | Honors Research | Advanced laboratory research. Results are presented in a poster session or other public forum. | 1 | CHEM 461 (Senior Project Report) and consent of instructor. |
| **CSU San Marcos** | 399A<br>399B | Special Problems in Chemistry – Laboratory | Individual investigation that involves a research project in the laboratory in collaboration with a faculty member in a related subdiscipline. A contract stating the proposed goals of the project will be | 1<br>2 | Consent of instructor. |

| | | | | | |
|---|---|---|---|---|---|
| | | | signed by both the student and the instructor. A written report summarizing the research findings must be submitted to the instructor at the end of each semester of work. May be repeated for a total of four (4) units of credit, but may not be substituted for CHEM 499. | | |
| | 499 | Senior Laboratory Thesis and Seminar | An original research project in the laboratory or in collaboration with a faculty member in the discipline. The student must consult with a faculty member in the discipline to decide on the research problem and then produce a research paper (approximately 10-20 pages) with a list of literature citations in American Chemical Society style. The research paper (thesis) must summarize the current state of knowledge on the research problem as well as the progress in the laboratory experiments aimed at the completion of the research project. The student will defend the thesis in a seminar to the faculty and students of the Department of Chemistry. The project will involve an average of six hours of supervised laboratory work each week. May be repeated for a total of four (4) units of credit. | 2 | One course in the subject area with a grade of B (3.0) or better and consent of instructor. |

| | | | | | |
|---|---|---|---|---|---|
| **Sonoma State Univer-sity** | 494 | Undergraduate Research | Individual investigation of either student- or faculty-initiated experimental or theoretical chemical problems under the supervision of a member of the chemistry faculty. May be taken only by petition to the Chemistry Department. May be repeated. | 1-6 | Chem 335B (Organic Chemistry); previous or concurrent enrollment in Chem 310B (Fundamentals of Physical Chemistry) and consent of instructor. |
| **CSU Stanis-laus** | 4980 | Individual Study | For qualified students desiring to do research or to pursue the study of some specialized topic. May be repeated for a total of 6 units. | 1-4 | Consent of instructor. |

Analysis of Table 2 reveals similar patterns of trends as those reflected in Table 1 for UC campuses. For example, all these research-related courses are upper division courses, with most of them requiring instructor consent as a prerequisite as well as a written and/or oral research report for the course. Also, similar to the UC institutions, none of these upper division research courses offer any formal training to the students prior to engaging in a research project. In addition, for the four most popular CSU transfer destinations for Mt. SAC students (Cal Poly Pomona, CSU Fullerton, CSU Los Angeles, and CSU San Bernardino), three of them have a GPA requirement as part of the prerequisite for the research courses.

During the research process for these CSU research courses, an important trend is perceived. With the exception of one campus (CSU Dominguez Hills), these research courses can partially satisfy the upper division core or elective requirements for degree completion in Chemistry for 20 CSU institutions. This demonstrates the importance of undergraduate research in education for the entire CSU system. Furthermore, for Cal Poly Pomona, CSU Fullerton, San Diego State University, CSU San Marco and Sonoma State University, a senior research project is required for all Chemistry majors. Also, for CSU Los Angeles and CSU Long Beach, participation in the research course is part of the requirement for graduating with Honors. This has strong implications for Mt. SAC students, since three of the above seven campuses are the most popular transfer destinations for them, with another two being common transfer sites. Consequently, the proposed courses in this sabbatical project need to address the specific requirements in these courses, providing support for the course guiding factors already described in the previous section for UC campuses. More importantly, offering research training courses at Mt. SAC would have a significant impact on properly preparing these students to finish their degrees successfully upon transferring.

**California Independent/Private Institutions**

For California independent universities and colleges, the top transfer destinations for Mt. SAC students are University of Phoenix, Azusa Pacific University, DeVry University, USC, and Chapman University. Since University of Phoenix and DeVry University do not offer degree programs in Chemistry, they are not included in this discussion. Research on all the remaining California independent institutions is concentrated on schools that offer degree programs in Chemistry, which narrows the list from around 80 institutions to about 30 schools. Furthermore, a close examination of all the popular transfer institutions for Mt. SAC students shows that most of the sites are located in close proximity to Mt. SAC, indicating that majority of students do no wish to be too far away. Based on this observation, the search is focused on 18 independent institutions within 50 mile radius of Mt. SAC, along with Stanford University. The following table summarizes the details of these undergraduate research-related courses in Chemistry for these institutions, with the three most transferred destinations for Mt. SAC students listed first.

**Table 3. Summary of undergraduate research-related courses in California independent institutions.**

| School | Course number | Course Title | Course Description | Number of Units | Prerequisites |
|---|---|---|---|---|---|
| **Azusa Pacific University** | 498 | Directed Research | This course provides instruction in research design and technique, and gives students experience in the research process. The one-unit expectation encompasses no fewer than 30 hours of work with accompanying reading, log writing, and seminar presentation within the department or in a university research symposium. No more than one unit may be used to fulfill preparatory readings requirement. | 1-4 | Junior or senior standing. |
| **Chapman University** | 299<br>499 | Research in Chemistry | For freshmen or sophomores. (Offered as needed.)<br>For juniors or seniors. | 1-3<br>1-3 | Consent of instructor. |
| | 497<br>498 | Senior Project | Chemistry capstone course. Working with a faculty mentor, a student designs a research project informed by a literature search during the first semester. During the second semester the student conducts laboratory research to test the project hypothesis, analyzes data, and writes a report summarizing the findings. The student makes an oral presentation to the chemistry faculty upon completion of all work. (Offered every year.) | 1<br>1-3 | CHEM 150 (General Chemistry Lab), 331 (Organic Chemistry Lab) for CHEM 497; CHEM 497 for CHEM 498. |

| | | | | | |
|---|---|---|---|---|---|
| **University of Southern California (USC)** | 490 | Directed Research | Individual research and readings. Not available for graduate credit.<br><br>*4 units of this course are required for a B.S. degree in Chemistry. | 2-8 | Departmental approval. |
| **California Institute of Technolo-gy (Cal Tech)** | 80 | Chemical Research | Offered to B.S. candidates in chemistry. Experimental and theoretical research requiring a report containing an appropriate description of the research work. Units in accordance with work accomplished. | variable | Consent of research supervisor. |
| **Claremont McKenna College**<br><br>**Pitzer College**<br><br>**Scripps College** | 188L | Senior Research in Chemistry | Seniors may apply to do laboratory or field investigation with a faculty member. The topic should be chosen by the end of the junior year. In this course library and lab materials are developed, research begun, and seminar discussion held with faculty members and students in the field of concentration. This is the first course for students doing a two-semester senior project. | 1 | Juniors and Seniors only. |
| ***Joint Science Depart-ment for these 3 colleges** | 190L | Senior Experimental Thesis in Chemistry | Senior laboratory or field investigation research is culminated and results are summarized in a written thesis and formal presentation. This is the second-semester course for those doing a two-semester research thesis. | 1 | Juniors and Seniors only. |

| | | | | | |
|---|---|---|---|---|---|
| **Concordia University** | 496 | Research in Chemistry | Hands-on introduction to chemical research with emphases on the research process, research skills and research methods. Laboratory research, library research, peer reviewed chemical abstracts and journals, electronic chemical databases, professional journal manuscript style guides and statistical analysis will be used in writing research manuscripts and making research presentations. | 2-4 | 16 units of chemistry courses or consent of instructor. |
| **Harvey Mudd College** | 151<br>152 | Research Problems | Two oral reports and a written thesis are required. (2 credit hours = a minimum of 6 hours, 3 credit hours = a minimum of 10 hours of laboratory per week: additional library time is required.) Topics in chemical literature will be covered in the first three weeks of the fall semester. | 2-3<br>2-3 | None specified. |
| **La Sierra University** | 498 | Directed Research | Completion of a laboratory research project under the direction of an on-campus faculty member or approved off-campus research supervisor. Minimum three hours laboratory per week per unit of credit. A maximum of four units may be applied toward the major. | 1-4 | Consent of the department chair. |
| **Loyola Mary-mount University** | 499 | Independent Studies: Directed Research | May be repeated for credit up to 6 semester hours. | 1-3 | None specified. |

| | | | | | |
|---|---|---|---|---|---|
| **Mount St. Mary's College** | 199 | Research in Chemistry | Research problems to be arranged with individual faculty members. | 1-3 | Consent of chemistry staff |
| **Occidental College** | 295<br><br>395 | Directed Research | Intensive study in an area of chemistry or biochemistry of the student's choosing under the direct supervision of a member of the faculty. | 2<br><br>*varies | Permission of the supervising instructor. |
| **Pepper-dine University** | 290 | Introduction to Research | Guided laboratory research in the field of chemistry. Students are introduced to data acquisition and analysis while working closely with their research director on current research projects. A written report is required upon completion of the work. | 1-2 | Taken only with consent of selected faculty member. |
| | 590 | Research in Chemistry | Original or classical research in the field of chemistry. A complete written report of work is required. | 1-4 | Taken only with consent of a selected faculty member. |
| **Pomona College** | 191A<br>191B | Senior Thesis. | The thesis requirement can be satisfied in one of two ways, beginning in the second semester of the junior year or in the first semester of the senior year: 1) The student writes a critical review of a topic of current interest and significance or 2) the student writes a thesis describing experimental work conducted in the laboratory of a faculty member. | *Not speci-fied. | Permission of department chair. |

| | | | | | |
|---|---|---|---|---|---|
| | | | For 191a: students writing a critical review select a topic and conduct library research; students writing an experimental thesis continue with laboratory work normally initiated through summer research or Chemistry 199. In both cases, they submit an abstract of their thesis for departmental review. For 191b: students begin writing the thesis and present it, or parts of it, orally at a departmental seminar. | | |
| | 199 | Selected Topics in Chemistry | Advanced reading and/or laboratory techniques in chemistry, usually by means of student-faculty collaborative research in the junior or senior year. | | Permission of instructor. |
| **Stanford University** | 190 | Introduction to Methods of Investigation | Limited to undergraduates admitted under the honors program or by special arrangement with a member of the teaching staff. Qualified students undertake research or advanced lab work not covered by listed courses under the direction of a member of the teaching staff. Each unit represents 4 hours of research per week. | 1-5 | CHEM 130 (Organic Chemistry Laboratory II).<br><br>Corequisite: CHEM 300 (Department Colloquium). |

| | | | | | |
|---|---|---|---|---|---|
| **University of La Verne** | 499 | Senior Seminar/Project | Culminating activity required by majors in all departments. Papers/theses/projects researched, prepared, and written under the guidance of a faculty member. Comprehensive exams or recitals required in some departments. Academically, Students must be in Good Standing to enroll in 499. Can be taken for letter grade only. Not challengeable. | 1-4 | Senior standing. |
| **University of Redlands** | 378 | Chemistry Research | Chemistry majors are required to complete 4 credits for graduation. Credit/No Credit grading only. | 1-4 | Written permission required. |
| **Whittier College** | 496 | Research | Individual research projects in selected areas of chemistry under the supervision of a faculty member. May be repeated for credit. | variable | Junior or senior standing, and permission. |

Again, the trends observed in Table 3 are similar to those reflected in Table 1 for UC campuses and Table 2 for CSU campuses. The majority of these research-related courses are upper division courses, which do not offer any formal training to the students prior to engaging in a research project. For the three most popular transfer destinations, both USC and Chapman University require directed research or senior project as part of the requirement for B.S. degree in Chemistry, while for Azusa Pacific University, the research course satisfies part of the degree requirements. In addition to these institutions, six other institutions – Stanford University, Harvey Mudd College, Pomona College, University of La Verne, La Sierra University and Mount St. Mary's College – also include the research course or senior project as a B.S. graduation requirement for all Chemistry majors. For all other institutions listed in Table 3, these research courses can partially satisfy the upper division core or elective requirements for degree completion in Chemistry.

In comparison to the UC and CSU websites, most of the websites the independent/private institutions provide more detailed information on how students can become involved in research as well as inform the students of the various research opportunities outside of class, such as summer research programs. It appears that these institutions place a stronger emphasis on undergraduate research and vigorously encourage students to engage in research at an early stage. Consequently, a larger percentage of their students participate in research as compared to students in UC or CSU institutions. These observations provide further support for the course guiding factors (already described in the previous section for UC campuses) for the two proposed research-training courses in this sabbatical project.

## Summary on Federal-Funded Programs

National Science Foundation (NSF) and National Institute of Health (NIH) offer various funding opportunities that promote and advance undergraduate education and research. Specifically, majority of government funding that support and encourage undergraduate research directly are programs that provide summer research experience to students, rather than courses in the curriculum. The following discussions describe the types of programs funded by each agency for undergraduate research participation and focus on program details.

### National Science Foundation (NSF)

***Program Overview.*** The primary source of NSF funding that provides undergraduate research opportunities is the ***Research Experiences for Undergraduates (REU) program***, which supports active research participation by undergraduate students in any of the areas of research funded by the NSF. The REU program seeks to expand student participation in all kinds of research, whether disciplinary, interdisciplinary, or educational in focus, by involving students in meaningful ways in ongoing research programs or in research projects specifically designed for the REU program. The REU program is a major contributor to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce. It draws on the integration of research and education to attract a diversified pool of talented students into careers in science and engineering, and to help ensure that these students receive the best education possible.

***REU sites.*** Nationwide, many four-year institutions have submitted proposals and currently about 60 institutions have received NSF funding to serve as a REU site to initiate and conduct projects that engage a number of students in research each summer. REU sites may be based in a single discipline or academic department, or on interdisciplinary or multi-department research opportunities with a coherent intellectual theme. REU projects may be carried out during the summer months, during the academic year, or both. Each site typically consists of about ten or more students per summer or year. REU Sites are encouraged to involve students in research who might not otherwise have the opportunity, particularly those from academic institutions where research programs are limited. Thus, a significant fraction of the student participants would come from outside the host institution or organization. For Mt. SAC students, this program would provide many appropriate and valuable educational experiences through participation in summer research, including the opportunity to engage as a student cohort at their possible transfer institution. In California, NSF-funded REU sites that offer summer research opportunities in physical sciences and/or engineering are:

- **UC campuses** – *UC Berkeley, UCLA, UC Irvine, UC Riverside*, UC San Diego, UC Santa Barbara, UC Davis, UC Santa Cruz, and UC San Francisco;
- **CSU campuses** – *CSU Fullerton, CSU Los Angeles, CSU San Bernardino*, San Diego State University, San Jose State University, and Humboldt State University;
- **independent/private institutions** – *USC*, Cal Tech, Harvey Mudd College, LA County Museum of Natural History, Pepperdine University, Loyola Marymount University, Santa Clara University, Oak Crest Institute of Science, SETI Institute, and California Academy of Sciences.

As indicated in the above list, there are 25 REU sites in California, with the eight most popular transfer destinations for Mt. SAC students highlighted in italics. This clearly reflects the vast opportunities available to Mt. SAC students, if they are aware of this type of program and are adequately prepared to obtain these positions.

***REU Program Activities.*** The main components of the REU program consist of active participation in a research project, development of student-faculty interaction with the faculty mentor, experience of being part of a student cohort, and interactions in a collegial setting. Most summer research programs are 10-weeks in duration, and participants receive a weekly stipend. Each REU site may offer additional activities that are specific to its educational objectives and environment. To provide a detailed account of what the students would experience in a REU program, the following describes the type of activities the students would participate in at CSU Fullerton's NSF-REU summer research program:

- Students experience first-hand how basic research is carried out, and to contribute consequentially;
- Each student is assigned to a specific research project in Chemistry or Biochemistry;
- Student will work closely with the faculty, post-docs, and graduate students;
- Seminars, lunch meetings, and social functions are organized to facilitate interaction between the undergraduates; and
- A strong supportive environment is provided for "late-bloomers" and re-entry students, and women and minority students are especially encouraged to apply.

To compare and contrast, the following describes the student experience at CSU Los Angeles' NSF-REU summer research program:

- Designed to give research opportunities to community college students from the Los Angeles Basin, especially students from groups underrepresented in the chemical sciences;
- Introduce students to research opportunities early in their academic careers so they will be motivated to continue their education in the chemical sciences and be exposed to potential career options;
- Areas of research include organic synthesis, biochemistry, inorganic synthesis, atmospheric chemistry, environmental monitoring, instrument development, and NMR spectrometry;
- Participants will work along side CSULA faculty and students;
- Students will present their research results at the end of the summer in a campus-wide symposium featuring posters displaying their findings and progress;
- Participants are required to attend several workshops throughout the summer that include *Laboratory Safety* and *Preparing a Research Poster*; and
- Other workshops on various laboratory techniques and scientific ethics are also available to REU participants.

***Application Process.*** For all REU programs, undergraduate student participants must be citizens or permanent residents of the United States or its possessions. Since NSF is particularly interested in increasing the numbers of women, underrepresented minorities, and persons with disabilities in research, REU projects are strongly encouraged to involve students who are members of these groups. (Underrepresented minorities are African Americans, Hispanics, American Indians, Alaska Natives, and Native Hawaiians or Other Pacific Islanders.) To participate, the students would apply directly to the REU site. Most applications are 2-3 pages long and available online. In addition to informational items such ethnicity, citizenship, contact information, current attendance at college/university, major, expected date of graduation, the following are often requested:

- a list of science and math courses taken in college and grades earned;
- research areas of interest in ranked order;
- academic plans upon graduating with B.S. degree;
- a description of previous scientific employment, lab experience, and/or research experience;
- a personal statement stating the reasons why the student wishes to conduct research and the relevance of this program to the student's career goals; and
- two recommendation letters, with at least one that can comment on laboratory skills.

**National Institute of Health (NIH)**

The mission of NIH, an organizational component of Department of Health and Human Services (HHS), is to improve human health by increasing scientific knowledge related to disease and health. This is accomplished through the conduct and support of biomedical and behavioral research, research training, research infrastructure, and communications. These efforts take place intramural (primarily at NIH) and extramurally (through grants, cooperative agreements, and contracts awarded to institutions of higher education, governmental organizations, non-profit research organizations, for-profit organizations, and individuals). The following sections describe the intramural and extramural funded programs that directly support undergraduate research.

***Intramural Programs.*** The ***Summer Internship Program (SIP)*** at NIH provide an opportunity for high school, college and graduate students, to spend a summer working side-by-side with some of the most talented, leading scientists in the world, in an environment devoted exclusively to biomedical research. Students may conduct research at the main campus in Bethesda, MD (which includes the Mark O. Hatfield Clinical Research Center and more than 1200 laboratories) or at the other 24 NIH institutes or centers around the country that focus on particular research areas. SIP awards cover a minimum of eight weeks, with students generally arriving at the NIH in May or June. Students who are selected receive a monthly stipend that is based on education level and experience. For trainees on the main campus, the Office of Intramural Training and Education sponsors a wide range of summer activities including a lecture series featuring distinguished NIH investigators, informal lunchtime talks on training for research careers, and a trainee poster day. The NIH provides additional opportunities such as the Science in the Cinema series.

To be eligible for the SIP program, candidates must be U.S. citizens or permanent residents, sixteen years of age or older, and are currently enrolled at least half-time in high school or an accredited U.S. college or university. Prospective candidates must apply electronically via the Internet. The electronic application requires submission of a curriculum vitae, a list of the applicant's publications, a cover letter describing the applicant's research interests and career goals, and the names and contact information for two references. Candidates are asked to specify the scientific methodologies or disease/organ systems that interest them.

In addition to the SIP program, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) sponsors a ***Biomedical Engineering Summer Internship Program (BESIP)*** for undergraduate biomedical engineering students who have completed their junior year of college. This ten week program (beginning of June – mid August) allows rising senior biomedical engineering students to participate, under the mentorship of world class scientists, in cutting-edge biomedical research projects in NIH laboratories in Bethesda, Maryland. Selected by a nationwide competition, the sixteen interns will have the opportunity to indicate preferences from a list of available NIH projects that involve areas of engineering or physical science expertise. The students will participate in group meetings, attend planned lectures and laboratory visits, and be encouraged to submit posters to the NIH Poster Day where summer interns from all disciplines present their projects.

To be eligible for the BESIP program, candidates must be U.S. citizens or permanent residents; have completed at least three years (6 semesters or 9 quarters) of undergraduate study in a Biomedical Engineering or Bioengineering degree program by the start of the summer; be returning to undergraduate school for at least one term following the summer program; and be present on the Bethesda campus to participate in the full ten week program. Prospective candidates must apply electronically via the Internet. The electronic application requires submission of a resume, an unofficial transcript, two recommendation letters, and a written essay that briefly discusses career goals, technical and research interests, the reasons for applying for this internship, a description of what the applicant would like to get out of the BESIP program. All selected summer interns will receive $4600 for the 10 week program.

***Extramural Programs.*** Most of the institutional research training grants funded by the NIH are directed at providing competitively trained undergraduate science/math students from minority/minority-serving institutions the opportunity to engage in mentored research, develop the skills and knowledge to successfully pursue Ph.D. degrees and future careers in biomedical and behavioral research. Consequently, these programs strongly encourage application of underrepresented minority students. Since Mt. SAC is a federally designated Hispanic-Serving institution, many Mt. SAC students belong in the targeted population for these programs. The following sections describe the five NIH-funded programs that focus on community college and/or undergraduate students at 4-year institutions. The first two programs (Bridges, BBSI) are open to community college students, while the remaining three programs (RISE, IMSD, MARC) are opportunities that students can pursue after they transfer.

The ***Bridges to the Baccalaureate Degree Program (Bridges)*** provides support to institutions to help students make transitions at a critical stage in their development as scientists – from two-year community colleges to full four-year baccalaureate programs. A key component of the Bridges program is the partnership between a four-year baccalaureate degree-granting institution with several community colleges, where community college students have the opportunity to participate in an enriched summer research program at the four-year institution. The Bridges program aims to increase the number of underrepresented scientists in biomedical research by specifically targeting underrepresented minority students. One of the program requirements for the community college partnership is that it must have a significant enrollment of underrepresented minority students. Currently, Mt. SAC is a partner with the UCLA Bridges program and has been for the past six years. This partnership has proven to be a wonderful opportunity for many students and indeed, all of the past participants have successfully transferred and completed their B.S. degrees in science. In addition, most of them continue to pursue their academic careers in professional school or graduate school.

There are a total of 54 Bridge program sites in the US, with 11 of them in California. Although Mt. SAC is a partner with the UCLA Bridges program, the students can also apply to any of these other Bridge program sites directly. Below is the list of Bridge program sites in California, with the top transfer destinations for Mt. SAC students in italics:

- UC campuses – *UCLA*, *UC Irvine*, and UC Santa Cruz;
- CSU campuses – *CSU Los Angeles*, CSU Long Beach, San Diego State University, CSU Dominguez Hills, CSU Sacramento, CSU San Marcos, San Francisco State University and San Jose State University.

Most of the Bridge programs offer opportunity to work closely with faculty on research projects in the biomedical sciences; regular workshops and seminars on the nature of academic life, writing and research skills and careers in biomedical research; informal meetings with faculty and students; as well as other cultural and educational activities on campus. Although program activities may vary in each Bridge program site, overall, the activities are specifically designed to support and encourage students who intend to pursue careers in teaching and/or research by preparing them for a four-year institution curriculum and its biomedical research environment.

To be eligible for the Bridge program at UCLA, candidates must: (1) be U.S. citizens or permanent residents; (2) be a student at a community college; (3) maintain a minimum 2.8 GPA in math and science courses; and (4) completed one semester of General Chemistry. The eligibility requirements for other Bridge programs are similar. To participate, students would apply directly to the Bridge program site, where applications are available online. Preference will be given to minorities who are underrepresented in biomedical research. For most of these Bridge programs, upon completion of the summer research project, each participant is required to give an oral presentation and submit a research report describing his/her research. All selected program participants will receive a stipend of about $300 per week.

The ***Bioengineering and Bioinformatics Summer Institutes (BBSI) Program***, jointly funded by the National Institute of Biomedical Imaging and Bioengineering (NIBIB) of the NIH and NSF, provides well-planned, interdisciplinary bioengineering or bioinformatics research and education experiences for undergraduate and early-stage graduate students majoring in the biological sciences, computer sciences, engineering, mathematics, and physical sciences. The purpose of the program is to increase the number of individuals deciding to pursue graduate careers in bioengineering and bioinformatics to advance biological and physical sciences research. Annually, every BBSI provides a combined total of approximately 15 undergraduate and graduate students with:

- didactic training experiences combining high quality formal course work with state-of-the-art research seminars to provide students with an interdisciplinary foundation in the fundamentals of bioengineering or bioinformatics; and
- mentored interdisciplinary bioengineering and bioinformatics research experiences, along with access to professional development opportunities.

Fifty percent or more of the student participants in each Summer Institute must come from outside the host institution.

Currently, there are 13 BBSI locations established in the country – CSU Los Angeles, Clemson University, Iowa State University, Massachusetts Institute of Technology, University of Minnesota, Oakland University, Oregon State University, New Jersey Institute of Technology, Pennsylvania State University, Texas A&M University, University of Pittsburgh, Virginia Commonwealth University, and Virginia Polytechnic Institute and State University. At CSU Los Angeles (one of the top transfer sites for Mt. SAC students), this program runs from mid June to late August for ten weeks and the students receive a $5000 stipend. The first three weeks are devoted to didactic training in bioinformatics and the students apply their knowledge in the remaining seven weeks towards a mentored research project of their choice at one of the eight research centers in the area.

To be eligible for the BBSI program at CSU Los Angeles, candidates must: (1) be U.S. citizens or permanent residents; (2) be an undergraduate student of sophomore standing or a student at a community college in the process of transferring to a four year program; (3) maintain a minimum 3.0 GPA in math, engineering, and science courses; and (4) major in a molecular life science-related field and have completed one C++ or object-oriented programming course OR major in a computer science-related field and have completed one molecular life science course. To participate, students would apply directly to the BBSI location, where applications are available online.

The Minority Biomedical Research Support (MBRS) at NIH awards grants to educational institutions with substantial minority enrollments to support research by faculty members; strengthen the institutions' biomedical research capabilities; and increase the interest, skills, and competitiveness of students and faculty in pursuit of biomedical research careers. Two of the three granting mechanisms of MBRS consist of ***Research Initiative for Scientific Enhancement (RISE)*** and ***Initiative for Maximizing Student Diversity (IMSD)***. The main difference between these two initiatives is that the RISE program is a student development program for minority-serving institutions, while the IMSD program is a student development program for research-intensive institutions. The goals of both programs are identical – to increase the number of students from underrepresented groups in biomedical and behavioral research who complete Ph.D. degree programs in these fields. An institution may apply for and hold only one RISE grant, and may not be currently receiving support from the MBRS Initiative for Maximizing Student Diversity (IMSD) Program.

Student participants in either the RISE or the IMSD programs will receive full financial support annually, specialized academic developmental programs, a strong science curricula, and high quality summer research experiences. Currently, there are 13 RISE or IMSD program sites in California, with the top transfer destinations for Mt. SAC students in italics:

- UC campuses – *UCLA*, *UC Irvine*, UC Santa Cruz, UC San Francisco;

- CSU campuses – *CSU Fullerton*, *CSU Los Angeles*, CSU Long Beach, CSU Northridge, San Diego State University, San Francisco State University, CSU San Marcos, CSU Dominguez Hills;
- Independent institutions – Loma Linda University.

To participate, students can apply directly to the RISE or IMSD program site via online applications. The application package is similar to other programs, consisting of an application form, a list of science and math courses completed, transcript, 1-2 pages of statement of purpose, and two recommendation letters.

The Minority Access to Research Careers (MARC) branch at NIH offers special research training support to 4-year colleges and universities with substantial enrollments of minorities. The branch's goals are to increase the number and competitiveness of underrepresented minorities engaged in biomedical research by strengthening the science curricula at minority-serving institutions and increasing the research training opportunities for students and faculty at these institutions. The ***MARC Undergraduate Student Training in Academic Research (MARC U*STAR) Program*** provides support for minority students to improve their preparation for a competitive graduate program and successful completion of a Ph.D. in the biomedical or physical sciences. Participants in the program receive financial support for tuition and fees, academic support, special mentoring, and high quality research experiences under the guidance of leading scientists, funding to travel to major scientific meeting to share research results, as well as enrichment through honors courses, workshops and seminars.

Currently, there are a total of 60 MARC U*STAR program sites in the nation, with 15 of them in California. Below is the list of MARC U*STAR program sites in California, with the top transfer destinations for Mt. SAC students in italics:

- UC campuses – *UCLA*, *UC Irvine*, *UC Riverside*, UC Santa Cruz;
- CSU campuses – *CSU Fullerton*, *CSU Los Angeles*, CSU Long Beach, CSU Northridge, San Diego State University, CSU Bakersfield, CSU Dominguez Hills, CSU San Marcos, San Francisco State University, San Jose State University;
- Independent institution – Mount St. Mary's College.

To participate, students can apply directly to the MARC U*STAR program site via online applications. The MARC U*STAR program is designed for students in junior and senior standing, majoring in biomedical sciences (Biology, Chemistry or Biochemistry) and physical sciences (Physics, Mathematics, Computer Science and Engineering). The application package is similar to other programs, consisting of an application form, a list of science and math courses completed, transcript, 1-2 pages of statement of purpose, and two recommendation letters.

## Summary on Exemplary Courses/Programs in Literature

Thorough reading and meticulous study of all the articles in issues of Journal of Chemical Education from years 2000 – 2007 and selected articles from earlier years, as well as publications from Council on Undergraduate Research and Chemical & Engineering News, along with attendance at two Council of Undergraduate Research conferences, reveal many cases of courses and programs that have successfully incorporated research components into the curriculum. To effectively summarize the similarities and differences in these exemplary cases, they are categorized in the following sections as classroom or non-laboratory courses, laboratory courses, and research programs at community colleges. Each section discusses the similarities and differences between the courses, as well as analyzing the key components of the courses. In addition, the report on literature research will conclude with a section that discusses the current views of undergraduate research in science education.

### Classroom or Non-Laboratory Research-Related Courses

In the literature, both undergraduate and graduate level research-related courses in classroom or non-laboratory settings are presented, ranging from a general education course in organic structure determination to a graduate course focused on research skills and ethics. Regardless of the level, the goals of the courses are similar – to teach students desirable research skills, integrate the classroom experience with that of the research laboratory, and effectively prepare them for conducting research. Thus, the selection of course topics is similar for most courses. Depth and breadth of topic coverage constitute as the main difference between the graduate and undergraduate level courses. To analyze, compare and contrast the courses, the key components of the courses are summarized in the following discussions.

i. ***Selection of Course Topics***. Most common topics covered in these courses include:

- Literature search and retrieval;
- Reading and understanding journal articles;
- Professional and research ethics;
- Scientific writing of review of journal article, and/or research reports and/or research articles and/or research proposals; and
- Oral or poster presentations.

Less common topics that are more specific to particular courses include overview of research opportunities, keeping a thinking log or research records, experimental designs, research lab safety practices, principles of instrumental methods, analysis of experimental and/or spectral data, and career development issues.

ii. ***Breadth and Depth of Topics***. Given the same topic, for undergraduate courses, the material is not treated as deeply or as comprehensively as the graduate courses, as limited by students' experience level and time constraints. For example, for literature search, in an undergraduate course, students are introduced to the typical online resource tools in the college library, whereas for graduate students, they are required to conduct various types of detailed searches based on chemical structure, author, topic, or registry number. In specialty courses that focus more specifically on writing skills, then the process of conducting literature search and various scientific writing is emphasized to include preparation of a literature review, research plan, research article and research proposal.

iii. ***Efforts to Generate Student Interest.*** For the various courses discussed in this section, no dedicated efforts to generate student interest in the course are presented, besides allowing the students to choose their own topics of interest for writing or presentation requirements. However, for courses that conducted student evaluations or surveys, the students often report a high level of interest, a sense of ownership and an overall positive attitude toward the course.

iv. ***Criteria for Student Project Selection.*** Most of these courses are preparatory courses that train students to participate in undergraduate or graduate research. Thus, for most of the course topics that require writing or presentation, instead of pre-determined topics by instructors, students are allowed to choose their own topics and many students often decide on research topics that they may participate in at a later time. Instructor input and guidance are provided, while instructor approval of the topics is required to ensure the students do not choose topics that are beyond the complexity level or time constraints of the course.

v. ***Criteria for Oral/Poster Presentations.*** For all the courses discussed in this section, oral PowerPoint presentations of typically 10-20 minutes to the entire class or before a larger departmental audience are required. To define the criteria for oral presentations, information such as general format, basics of good graphical design, and tips for preparation and delivery of an effective presentation are often discussed first. Some courses require students to prepare and distribute an abstract and/or a set of handouts, as well as fielding questions from the audience. One of the courses utilizes a critical appraisal approach, where the presentation is evaluated by self and others, aiming to mimic the type of interaction that often occurs in the science community.

vi. ***Criteria for Written Reports.*** For most scientific papers or research reports, the basic components consist of abstract, background/introduction, purpose, experimental methods, results, conclusion and references. The required format is often the standard journal format defined by "The American Chemical Society (ACS) Style Guide." For other types of scientific writing such as review of literature articles or preparation of research plan/proposal, then specific guidelines or handouts are provided to the students.

vii. ***Methods of Evaluation***. Similar to most academic courses, the students are graded based on homework or assignments, in-class tests, written reports, oral presentation and final exam. In most of these courses, students have the opportunity to improve their grade on written assignments, upon receiving guidance from instructors and making revisions to their reports.

viii. ***Assessment of the Course***. Some of the courses do not discuss assessment, and for others that conduct assessment, the most common tool utilized are surveys, including:

- Standard departmental course evaluations;

- Pre- and post-course student surveys developed specifically for the course, with questions on student attitudes and skills acquired; and
- Faculty surveys to determine whether the course is accomplishing its objectives.

**Laboratory Research-Related Courses**

Due to the hands-on nature of science experimentation and instrumentation, in the literature, there are more articles on laboratory research-related courses than those on classroom or non-laboratory courses. In contrast to the classroom or non-laboratory courses, all of the laboratory research-related courses found in literature are undergraduate courses. This is a reasonable finding, since in graduate school, the types of hands-on experimental and instrumental skills required may be very topic oriented, defined by the individual research interest of the faculty, and thus a general course may not be an effective method of training.

In the literature, most of the courses address second-year and advanced students, since these students would have already completed at least one year of general chemistry and possess some fundamental chemistry knowledge as well as basic laboratory skills. The notable exceptions include a general education course and a general chemistry course, both aim at students with limited high school chemistry background. Amongst the mainstream laboratory research-related courses aimed at second-year or advanced students, most of them are organic chemistry courses, with a few courses being inorganic or analytical. Thus, the selection of laboratory topics and experiments is similar for courses in the same area of chemistry, and varies greatly from courses in different fields of chemistry. Regardless of the focus of the course, the goals of the courses are similar –

to teach students essentials of research experimental design, develop or refine hands-on experimental skills, provide hands-on instrumentation experience, and effectively prepare them for conducting their own research. To analyze, compare and contrast the courses, the key components of the courses are summarized in the following discussions. Some of the components are similar to those discussed earlier for classroom or non-laboratory courses, while others are specific to the nature of a laboratory course.

i. ***Selection of Laboratory Topics or Experiments/Projects***. For research-related laboratory courses in organic chemistry, the most common topics in these courses include:

- Short lectures on laboratory safety, experiment overview, scientific writing, chemical information source, literature search and science ethics;
- Keeping a laboratory notebook or experimental record;
- Guided-inquiry, discovery-based experiments or modules involving various instrumentation;
- Project-based, student-designed multi-step synthesis experiments of organic compounds of the students' choice;
- Adaptation of faculty's research projects into the laboratory, where projects utilize a combinatory synthesis approach;
- Multi-step synthesis (3-5 steps) experiments of specific compounds and natural products;
- Integration of literature search, chemical information topics and resources for each laboratory experiment or project;

- Incorporation of molecular modeling in guided-inquiry experiments or research projects;
- Scientific writing for laboratory reports and/or research proposals; and
- Oral or poster presentations.

For organic laboratory courses where the research project is one of the components rather than the entire course, then students learn the basic lab techniques such as recrystallization, extraction, simple and fractional distillation, thin-layer chromatography, as well as purification and characterization of product through the traditional routine experiments. For research-related laboratory courses in organic chemistry, the nature of the course and many of the topics are similar to the ones listed above for organic chemistry. The main difference is the type of compounds chosen for experiments and projects, where one is organic and the other is inorganic.

ii. ***Selection of Instruments Utilized in Teaching and Projects***. For research-related laboratory courses, the most common analytical instrumentation utilized in traditional experiments and research projects include:

- Infrared spectroscopy (IR) for liquid and solid compounds;
- Proton- ($^1$H) and carbon-based ($^{13}$C) nuclear magnetic resonance spectroscopy (NMR) for liquid and solid compounds;
- Gas Chromatography (GC) for liquid and gas compounds;
- Gas Chromatography coupled with Mass Spectrometry (GC-MS) for liquid and gas compounds; and
- Ultraviolet-Visible spectroscopy for liquid and solid compounds.

Through these courses, the students are exposed to, and trained in the use of, a variety of the analytical instrumentation (listed above) in the context of problem solving.

iii. ***Breadth and Depth of Topics***. Most of the courses in the same area of chemistry address similar experimental techniques and instrumentation. In many cases, the length of time devoted to the research projects defines the comprehensiveness of the student's experiences. For example, in courses where the research project is only one of the components, then the students may only be able to participate in one research project for about 4-6 weeks. In contrast, for courses where the entire course is research-based, then the students would either engage in several different research projects to be exposed to various learning experiences or in one lengthy research project where more meaningful results can be obtained.

iv. ***Efforts to Generate Student Interest***. Similar to the classroom or non-laboratory courses, these research-based laboratory courses do not demonstrate any dedicated efforts to generate student interest in the course. However, since in many courses, the students are allowed to choose their own research project and make independent decisions, then a high level of interest and a sense or ownership in the projects are generated. This positive attitude is well reflected in the student evaluations or surveys.

v. ***Criteria for Student Project Selection***. In contrast to classroom or non-laboratory courses where most students are allowed to choose their own topics, the choices for student project in the laboratory are more limited due to constraints on availability of chemicals and instruments. For projects where students are encouraged to select their own synthesis project, then instructor input and guidance are provided to ensure the students do not choose projects that are beyond the complexity level or time constraints of the course. In research-based organic chemistry laboratory courses where a faculty's research combinatory synthesis project or other type of combinatory project is adapted as student project, then the student can exercise a large degree of academic freedom in choosing their own starting materials and product to work with. The process of searching the literature, making one's own decision, and designing the experimental procedure is very advantageous for the students since it allows them to experience real research first-hand and develop a sense of ownership of the project.

vi. ***Criteria for Oral/Poster Presentations.*** In contrast to classroom or non-laboratory courses, poster presentation serves as an effective and popular method of communication for laboratory courses. To define the criteria for poster presentations, information such as general format, use of presentation software, tips for preparation of a 12-panel poster, and delivery method for an effective presentation are discussed thoroughly with the students. The required contents for poster presentation include a title with authors, an abstract less than 200 words, introduction with reaction schemes, full experimental section written in the format of journal articles, spectra with interpretation, and conclusion or summary. For oral presentations, the guidelines and requirements are similar to those discussed earlier for classroom or non-laboratory courses.

vii. ***Criteria for Written Reports.*** An integral part of writing for a research-based laboratory course involves the diligent keeping of an accurate laboratory notebook, where clear written documentation of experimental procedures and observations are strongly emphasized. To define the criteria for laboratory notebook, formal laboratory reports and research proposals, very specific guidelines are provided to the students and discussed thoroughly. For the organic courses, requirements for formal reports include an equation describing the chemical reaction performed, a table of reagents used, a detailed experimental procedure, the yield and characterization of the product(s), a detailed analysis of each experimental and spectral data, and discussion or conclusion. Some courses choose to adopt the format for scientific journals as the criteria for formal reports. For combinatory synthesis projects where students often design their own experimental procedure, then a research proposal is required where students have to define a reaction scheme, a detailed procedure for each synthetic step, proposed methods for purification, proposed methods for product identification including anticipated spectral data, and a comprehensive list of chemicals and special glassware needed.

viii. ***Methods of Evaluation***. Being a laboratory course, most of the student evaluations involve grading systems based upon the students' mastery of specific laboratory skills, proficient use of instruments, improved written communication skills as demonstrated through laboratory notebooks and formal reports, and effective oral communication skills as evidenced by oral or poster presentation. Many courses allow students opportunities to repeat their laboratory work until they receive a satisfactory grade.

ix. ***Assessment of the Course***. Similar to the classroom or non-laboratory courses, some of the courses do not discuss assessment, and for others that conduct assessment, the most common tool utilized are surveys, including:

- Standard departmental course evaluations;
- Course student surveys developed specifically for the course, with questions on how students gauge their perceived mastery of laboratory skills and their perception of a research-based laboratory; and
- Faculty surveys to determine whether the course is accomplishing its objectives.

For one of the courses, independent reviews of student work by chemistry professors from other institutions are conducted in addition to the above assessment.

## Research Programs at Community Colleges

As expected, due to the fact that research is not an expectation nor a job requirement, and time constraints from heavy teaching loads, as well as the limitation of resources and instrumentation, undergraduate research at community colleges are few and rare. In the literature, the earliest reference to conducting research at community colleges dates back to only ten years ago, demonstrating that this is a relatively new concept for the science community.

In the nation, there are many community colleges that share partnerships with nearby four-year institutions and encourage students to participate in summer research opportunities. However, as far as involving their students in research directly on campus (with or without collaboration of nearby universities), the literature only cites three community colleges. Similar to the four-year institutions, most of these efforts are made possible via grant support from federal funding agencies such as the National Science Foundation and the National Institute of Health. The grant support provides the funding to purchase advanced instrumentations necessary for science research. One college has incorporated a five-week research project into a Quantitative Analysis II course where students design, conduct, analyze, and present their own project. At the other two colleges where students are actively participating in research, past efforts have been successful and have led to journal publications as well as presentations at professional conferences.

As the importance of engaging students in research as early as possible in their undergraduate education is becoming widely recognized, it is suggested in literature that community colleges should develop avenues to offer research experiences to their students. Suggestions include investigating the feasibility of offering an Introduction to Undergraduate Research course to science students, as well as systematic changes within the community college framework where compensation for directing student research are offered to faculty.

## Current Views of Undergraduate Research in Education

In recent years, the national recognition of the pedagogical value of undergraduate research has been reflected by many articles in literature, as well as funding opportunities from the National Science Foundation (NSF). In 1997, NSF awarded three-year grants of $500,000 to 10 research-intensive universities as Recognition Awards for the Integration of Research and Education (RAIRE) and in the following year, a second set of Awards for the Integration of Research and Education (AIRE) were given to 10 baccalaureate institutions. These awards are part of a larger effort being undertaken by many educators around the country to expand student involvement in research or discovery-based activities and integrate research into undergraduate education. Although the 20 awarded institutions are very different (public and private, large and small, urban and rural, geographically diverse, etc.), the programs implemented at these institutions are each successful in engaging more undergraduates from various disciplines (humanities, arts, social sciences, and physical sciences) in inquiry-based learning activities. Their collective efforts and methods of effectively pursuing research and inquiry-based education on campus have been reported in literature in 2003 and 2004. In addition, the principle investigators of these RAIRE/AIRE and faculty at these 20 institutions have determined the following activities to be some of the essential features of undergraduate research:

- Students should read scientific literature;
- Students should design some aspect of the project; opportunities should exist for exploration of the students' ingenuity and creativity;
- Students should work independently and have an opportunity to work on a team;
- Students should feel ownership of the project and increased confidence;
- Students should use careful and reproducible lab techniques, as well as demonstrating a mastery of the techniques necessary to research; and

- Students should have an opportunity for oral and written communication.

Not surprisingly, many of these essential features of undergraduate research are components of the research-related courses in most of the four-year institutions in California and ones described in literature, as well as the summer research programs sponsored by NSF and NIH.

In NSF's strategic plan for years 2001-2006, one of its goals is to invest in "people to develop a diverse, internationally competitive, and globally engaged workforce of scientists, engineers, and well-prepared citizens." To accomplish this goal, the integration of research and education is cited as one of the core strategies. The significance of undergraduate research is further emphasized by NSF's dedicated efforts in creating grant opportunities such as the "Undergraduate Research Centers" that began in 2003 (now known as "Undergraduate Research Collaboratives"). This grant program supports new models and partnerships with the potential to include first- and second-year college students in undergraduate research, as well as to enhance the research capacity, infrastructure, and culture of participating institutions. In 2004, NSF hosted a workshop on "Implementation of Undergraduate Research Centers" to share the successful strategies and best practices, as well as to explore ways to improve the implementation of the program.

On a national level, to promote the integration of undergraduate research in education, many collaborative efforts between different organizations have been described in literature. In 2003, Undergraduate Research Summit in Chemistry, supported by NSF, was held and attended by leaders from the chemistry community, and participants that represented a variety of constituencies including different types of public and private undergraduate institutions, doctoral-granting institutions, industry, national laboratories, and funding agencies. The purpose of the summit was to examine the issues involved in undertaking and sustaining chemistry research at primarily undergraduate institutions (PUIs) and to publish a report that provides recommendations on how to enhance the number, quality, productivity, and visibility of chemistry research programs at PUIs. Summit participants recommend that departments should strive to develop a research-supportive curriculum, where students are exposed earlier in the curriculum to experiences directed at developing critical research skills that include and go beyond the technical laboratory experience. The final report of the summit suggests that components of a research-supportive curriculum should include:

- Search, read and evaluate the chemical literature;
- Articulate a concise, approachable research question and its context;
- Design and execute experimental approaches to a research question employing appropriate instrumentation and techniques;
- Collect, assess and communicate experimental data and scientific information;
- Critically interpret the data obtained through their experiments and solve problems as they arise; and
- Communicate clearly the nature of the research and its significance.

In recent years, some of the practices, courses and programs that create a research-supportive curriculum described in the literature include: (1) problem-based learning where an authentic problem initiates the learning process involving a group of students that are engaged in a student-centered, cooperative, and interactive exploration and design of a suitable solution; and (2) project-based laboratories involving inquiry-driven scientific investigations that allow students to formulate the questions to be addressed and to design the experiments to answer these questions.

Recent literature portrays several significant collaborations between different organizations to promote the integration of undergraduate research in education. First, in 2006, Council of Undergraduate Research (CUR) collaborated with the Association of American Colleges and Universities (AACU) to publish journal articles that highlight undergraduate programs that integrate students into the research community through mentored experiences across all disciplines, providing students with hands-on opportunities to participate in original research projects. Second, CUR and the National Conference on Undergraduate Research co-hosted a new initiative entitled "Initiating and Sustaining Undergraduate Research" in May 2007. The purpose of this initiative is to provide new directors of undergraduate research programs the means to develop and effectively run their programs and to help seasoned directors disseminate best practices and further build or improve their programs. Third, the most recent collaborative effort exists between CUR and the National Council of Instructional Administrators (NCIA). Funded by a two-year planning grant from NSF, this collaboration seeks to explore issues related to undergraduate research in two-year programs, identify potential partners, develop resources, and propose a plan for establishing new partnerships that will broaden the involvement of students in research. To accomplish this goal, a series of regional workshops have been and continue to be hosted in 2007 and 2008 to address institutions that do not have a tradition or culture of campus-wide engagement in undergraduate research. The workshops will assist participating institutions in articulating their goals for institutionalizing undergraduate research, as well as developing strategies to achieve these goals on their campuses, in addition to fostering communities of scholars among the participating campuses.

It is evident from the various efforts and collaborations described above that the pedagogical value and importance of undergraduate research in education have been widely recognized on a national level in literature as well as by federal funding agencies and various organizations. Recent reports indicate that a research-supportive curriculum that provides opportunities for inquiry-based activities and research-like experiences serves as an effective mechanism for spurring interest in science and retaining students in science disciplines, as well as for engaging students in the intellectual inquiry necessary to develop them into innovative and productive scientists.

## REFERENCES


- ***Websites for UC campuses*** that link directly to the research-related courses, listed in the same order as in Table 1. Last accessed on June 2007 to check for accuracy and updates.

  http://sis.berkeley.edu/catalog/gcc_list_crse_req?p_dept_name=Chemistry&p_dept_c d=CHEM

  http://www.registrar.ucla.edu/catalog/catalog05-07-2-38.htm

  http://www.editor.uci.edu/06-07/ps/ps.3.htm

  http://www.catalog.ucr.edu/current/chem.html#Ucourse

  http://registrar.ucdavis.edu/UCDWebCatalog/programs/CHE/CHEcourses.html

  http://chem-courses.ucsd.edu/catalog.html#lowerdiv

  http://www.catalog.ucsb.edu/ls/chem.htm#LowDiv

  http://reg.ucsc.edu/catalog/html/programs_courses/chemCourses.htm

  http://registrar.ucmerced.edu/docs/UC_Merced_2006-2007_General_Catalog.pdf

- ***Websites for CSU campuses*** that link directly to the research-related courses, listed in the same order as in Table 2. Last accessed on June 2007 to check for accuracy and updates.

  http://www.csupomona.edu/~chemistry/undergrad/courses.htm#top

  http://www.fullerton.edu/catalog/academic_departments/chem.asp#courses

  http://catalog.calstatela.edu/NXT/gateway.dll?f=templates$fn=default.htm$3.0$vid=c alstate:current

  http://chem.csusb.edu/Chem/Studentinfo/Courses.html

  http://www.csub.edu/05-07Catalog/chemistry.htm

  http://chemistry.csuci.edu/course_descriptions.htm

  http://www.csuchico.edu/catalog/chem/offerings.html

  http://www.csudh.edu/Catalog/200507/22%20chemistry.htm

http://www.sci.csuhayward.edu/chemistry/courses.html

http://www.csufresno.edu/catoffice/current/chemcrs.html

http://www.humboldt.edu/~humboldt/catalogpdfs/courses/chem.pdf

http://www.csulb.edu/divisions/aa/catalog/06-07/depts/chem/courses/

http://www.csun.edu/chemistry/Catalog.html

http://aaweb.csus.edu/catalog/current/catdiscour.asp?course=CHEM*

http://www.chemistry.sdsu.edu/research/ugrsrch.php

http://www.sfsu.edu/~bulletin/courses/chem.htm

http://info.sjsu.edu/web-dbgen/catalog/departments/CHEM-courses.html

http://www.calpoly.edu/%7Eacadprog/2007pubcat/bus-edes.pdf

http://www.csusm.edu/academic_programs/catalog/2006-08_Catalog/2-Color_FINALv2.pdf#zoom=100&page=238

http://www.sonoma.edu/chemistry/Catalog.html#Descriptions

http://web.csustan.edu/Catalog/Colleges/NaturalSciences/DepartmentsPrograms/Chemistry/index-Courses.html

- ***Websites for California independent/private institutions*** that link directly to the research-related courses, listed in the same order as in Table 3. Last accessed on June 2007 to check for accuracy and updates.

http://apu.edu/clas/biochem/chemistry/requirements/

http://www1.chapman.edu/catalog/current/ug/chemistry.html
http://www.usc.edu/dept/publications/cat2006/schools/college/chem/courses.html

http://chemistry.caltech.edu/courses/index.html

http://www.claremontmckenna.edu/admission/catalog/2006-2007/Science.pdf

http://www.cui.edu/academicprograms/undergraduate/naturalscience/chemistry/index_ektid2086.aspx http://www.dof.hmc.edu/catalogue06-07/

http://www.lasierra.edu/departments/chemistry/coursesoff.html

http://www.lmu.edu/AssetFactory.aspx?did=11201

http://www.msmc.la.edu/pages/4303.asp

http://departments.oxy.edu/chemistry/chemistrycatalog.htm

http://seaver.pepperdine.edu/admission/resources/catalog/2007seavercatalog.pdf

http://www.chemistry.pomona.edu/Chemistry/chem_courses0405.pdf

http://www.stanford.edu/dept/registrar/bulletin/bulletin06-07/pdf/Chemistry.pdf

https://banweb.ulv.edu/pls/hp1prd1/bwckctlg.p_disp_course_detail?cat_term_in=200730&subj_code_in=CHEM&crse_numb_in=499

http://www.redlands.edu/x25504.xml

http://web.whittier.edu/academic/chemistry/COURSE_DESCRIPTIONS.html

- ***Websites for federal funding agencies*** that link directly to the funded undergraduate research programs. Last accessed on June 2007 to check for accuracy and updates.

**NSF-REU websites:**

http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517&org=NSF

http://www.nsf.gov/crssprgm/reu/reu_search.cfm

http://chemsrvr2.fullerton.edu/reu/reu.html

http://www.calstatela.edu/dept/chem/reu.htm

**NIH websites**:

http://www.training.nih.gov/student/sip/

http://www.nibib.nih.gov/Training/UndergradGrad/besip/home

http://www.nigms.nih.gov/Research/Mechanisms/BridgesBaccalaureate.htm

http://bbsi.eeicom.com/

http://www.nigms.nih.gov/Research/Mechanisms/MBRSAwards.htm

http://www.nigms.nih.gov/Training/Mechanisms/MARC/USTARAwards.htm

- ***Literature citations for exemplary research-related courses/programs.***


**Classroom or Non-Laboratory Research-Related Courses**

Toh, C. An Experiential Research-Focused Approach: Implementation in a Nonlaboratory-Based Graduate-Level Analytical Chemistry Course. *J. Chem. Educ.* **2007**, *84*, 639-642.

Schepmann, H. G.; Hughes, L. A. Chemical Research Writing: A Preparatory Course for Student Capstone Research. *J. Chem. Educ.* **2006**, *83*, 1024-1028.

Salter, C. "Research Supportive" Curricula in the Freshman & Sophomore Years. Council on Undergraduate Research 2006 National Conference, DePauw University, IN, June 2006.

Thompson, K. The Catalyst Seminar: Introducing Freshmen to the Culture of Research. Council on Undergraduate Research 2006 National Conference, DePauw University, IN, June 2006.

Clough, S. C.; Kanters, R. P. F.; Goldman, E. W. Chem 111: A General Education Course in Organic Structure Determination. *J. Chem. Educ.* **2004**, *81*, 834-836.

Schildcrout, S. M. Learning Chemistry outside the Laboratory: Novel Graduate and Undergraduate Courses in Research Methodology. *J. Chem. Educ.* **2002**, *79*, 1340-1343.

Mabrouk, P. A. Research Skills & Ethics – A Graduate Course Empowering Graduate Students for Productive Research Careers in Graduate School and Beyond. *J. Chem. Educ.* **2001**, *78*, 1628-1631.

**Laboratory Research-Related Courses**

Newton, T. A.; Tracy, H. J.; Prudente, C. A Research-Based Laboratory Course in Organic Chemistry. *J. Chem. Educ.* **2006**, *83*, 1844-1849.

Hollenbeck, J. J.; Wixson, E. N.; Geske, G. D.; Dodge, M. W.; Tseng, T. A.; Clauss, A. D.; Blackwell, H. E. A New Model for Transitioning Students from the Undergraduate Teaching Laboratory to the Research Laboratory – The Evolution of an Intermediate Organic Synthesis Laboratory Course. *J. Chem. Educ.* **2006**, *83*, 1835-1843.

Wink, D. CASPiE: A Program to Include Research as Part of the Mainstream 1st and 2nd Year Laboratory Curriculum. Council on Undergraduate Research 2006 National Conference, DePauw University, IN, June 2006.

Clough, S. C.; Kanters, R. P. F.; Goldman, E. W. Chem 111: A General Education Course in Organic Structure Determination. *J. Chem. Educ.* **2004**, *81*, 834-836.

Hanks, T. W.; Wright, L. L. Techniques in Chemistry: The Centerpiece of a Research-Oriented Curriculum. *J. Chem. Educ.* **2002**, *79*, 1127-1130.

Vallarino, L. M.; Polo, D. L.; Esperdy, K. Development of a Research-Oriented Inorganic Chemistry Laboratory Course. *J. Chem. Educ.* **2001**, *78*, 228-231.

Davis, D. S.; Hargrove, R. J.; Hugdahl, J. D. A Research-Based Sophomore Organic Chemistry Laboratory. *J. Chem. Educ.* **1999**, *76*, 1127-1130.

Ruttledge, T. R. Organic Chemistry Lab as a Research Experience. *J. Chem. Educ.* **1998**, *75*, 1575-1579.

Dunn, J. G.; Phillips, D. N. Introducing Second-Year Chemistry Students to Research Work through Mini-Projects. *J. Chem. Educ.* **1998**, *75*, 866-869.

Kharas, G. B. A New Investigative Sophomore Organic Laboratory Involving Individual Research Projects. *J. Chem. Educ.* **1997**, *74*, 829-831.

**Research Programs at Community Colleges**

Brown, D. R. Undertaking Chemical Research at a Community College. *J. Chem. Educ.* **2006**, *83*, 970-972.

Turner, R. E. The MATRIX – Multicultural Alliance for Technology, Research, and Information Exchange. *J. Chem. Educ.* **2006**, *83*, 19-22.

Gaglione, O. G. Underground Existence of Research in Chemistry in Two-Year College Programs. *J. Chem. Educ.* **2005**, *82*, 1613-1614.

Chan, C. MBRS Programs at East Los Angeles College. *J. Chem. Educ.* **1999**, *76*, 15-16.

Whipple-VanPatter, G. Research Not Foreign to Two-Year Colleges. *J. Chem. Educ.* **1998**, *75*, 1210.

## Current Views of Undergraduate Research in Science Education


Karukstis, K. The Impact of Undergraduate Research on America's Global Competitiveness. *J. Chem. Educ.* **2007**, *84*, 912-914.

Karukstis, K. Alliances to Promote Undergraduate Research. *J. Chem. Educ.* **2007**, *84*, 384-385.

Karukstis, K. A Council on Undergraduate Research Workshop Initiative to Establish, Enhance, and Institutionalize Undergraduate Research. *J. Chem. Educ.* **2006**, *83*, 1744-1745.

Undergraduate Research, *Peer Review*, Association of American Colleges and Universities, 2006, *http://www.aacu.org/peerreview/pr-wi06/index.cfm* (accessed June 2007)

Karukstis, K. Showcasing Successful Practices That Enhance a Research-Supportive Undergraduate Curriculum. *J. Chem. Educ.* **2005**, *82*, 1440-1441.

Henry, C. M. Getting a Head Start – Programs Introduce Undergraduates to Laboratory Research in Their Freshman Year. *Chem. Eng. News* **2005**, 83, 39-41.

Henry, C. M. Undergraduate Research Makes a Difference. *Chem. Eng. News* **2005**, 83, 37-38.

Implementation of Undergraduate Research Centers: A Report on a National Science Foundation Workshop, National Science Foundation, 2005, *http://www.scu.edu/cas/research/upload/URCworkshopfinalreport-3.pdf* (accessed June 2007)

Karukstis, K. Reinvigorating the Undergraduate Experience with a Research-Supportive Curriculum. *J. Chem. Educ.* **2004**, *81*, 938-939.

Enhancing Research in the Chemical Sciences at Predominantly Undergraduate Institutions: A Report from the Undergraduate Research Summit, Bates College, Lewiston, ME, August 2003, *http://abacus.bates.edu/acad/depts/chemistry/twenzel/finalsummitreport.pdf* (accessed June 2007)

Lopatto, D. The Essential Features of Undergraduate Research. *Council on Undergraduate Research Quarterly* **2003**, *23*, 139-142.

National Science Foundation 2000. NSF GPRA Strategic Plan FY 2001-2006, NSF Publication 0104. *http://www.nsf.gov/pubs/2001/nsf0104/start.htm* (accessed June 2007)

# PROJECT ACTIVITIES

***Part 2: Design of the 1$^{st}$ Course – "Introduction to Science Research"***

## COURSE GOALS AND PEDAGOGY

Based on the research results from Part 1 – Research and Investigation on Research Training Courses, it is evident that while there are abundant research opportunities available to Mt. SAC students, the need for science research training courses to properly prepare students for these valuable experiences is imperative. To address this crucial need, the goals of the first proposed course, "Introduction to Science Research," are to provide an overview on the various components of science research and prepare the students with basic knowledge to get involved in research.

Specifically, to achieve these goals, the pedagogical approach to the course is based on the valuable insights gained through the research and investigation process of this sabbatical project. First, to determine the various components of science research that the students should be expose to, conclusions are drawn from the exemplary research-related courses found in literature (especially the classroom or non-laboratory courses), as well as from articles in literature that provide the current views on undergraduate research. Based on discussions presented in part 1 of this sabbatical report, the essential components of science research this course should educate the students on include:

- Understanding of the scientific method;
- Awareness of ethics in science research;
- Knowledge in conducting a literature search;
- Reading and comprehension of science literature;

- Familiarity with the research environment;
- Ability to communicate through writing; and
- Ability to communicate through oral presentation.

To address the second goal of the course, in addition to exposing the students to the nature of research through the above topics, the students need to be aware of and prepare for the type of research opportunities available to them. Specifically, the results from the research and investigation process in part 1 indicate that there two types of research opportunities available to Mt. SAC students:

- Summer research programs (funded by the NSF or the NIH) – available to students both before and after transfer; and
- Upper-division research-related courses – available to students immediately after transfer.

In addition, there are research scholarships and stipends for the academic year (funded by the NIH) that transferred students can apply to. To properly prepare the students to get involved in research via these opportunities, this course will provide the students with knowledge on the details of course/program requirements and application process (as summarized and discussed in part 1 of this sabbatical report under Courses Offered by California Universities/Colleges and Federal-Funded Programs).

Being an introductory course, the primary role of this course is not to cover every aspect of science research training, but rather to attract students to learn about science research and stimulate their interests to pursue research opportunities. Thus, it would be appropriate as a one- or two-unit course; this would not place too much time constraint or burden on interested students that already have planned or committed to a full academic schedule. The only prerequisite for the course is the completion of the first semester of General Chemistry (Chem 50 at Mt. SAC), the first chemistry course in the core requirements for most science majors. This should allow a large percentage of the science major students to enroll in the course, since most students take Chem 50 either in their first or second semester. By completing Chem 50, the students would have a basic understanding of chemistry, preliminary training in fundamental laboratory skills, and the ability to comprehend the various research components or topics. In addition, for most of the summer research programs open to community college students, the minimal course requirement consists of completion of the one-year of general chemistry sequence.

## Course Topics and Activities

To accomplish the goals of the course, a set of course topics and planned activities are selected. Again, the specific selection of the topics are guided by the patterns of similarity observed in the research-related course requirements in four-year institutions in California, program requirements for the federal-funded summer research opportunities, and components of the exemplary classroom or non-laboratory research-related courses in the literature. The following discussion outlines the course topics and describes the planned activities for each topic.

i. ***Why Do Research.*** Most students that are planning ahead for their academic future are aware of the fact that participation in academic research is advantageous to their future applications to graduate or professional school. However, students tend to think of research as another task that needs to be completed; in fact, very few have considered or thought about the personal benefits such an experience can bring to them. Activities in this course will begin with an informal discussion on:

- Reasons why participation in research can be beneficial to them on a personal level; and
- Potential impact of research experience on their future academic or career endeavors.

ii. ***Introduction to Scientific Method.*** Although students have been exposed to this topic in their previous chemistry or science courses, but most students have not seen or experience the application of scientific method. Also, in science research, the stages and progress of scientific inquiry may not fit the order of steps usually defined in most textbooks. In this course, the scientific method will be reintroduced in the context of research, specifically, the activities will involve:

- Scientific method in research – the "Inquiry Wheel" and significance of science literature; and
- Mentos and the scientific method – a case study with hands-on applications.

iii. ***Ethics in Science Research.*** While academic integrity is a topic that is included in almost every class syllabus and college catalog, it is also a topic that most students know very little about, especially when it is in the context of conducting science research. Thus, activities on this topic will include:

- Guided class discussion on ethics in science research – intellectual property, confidentiality, record keeping, data analysis, and publication practices; and
- Case studies from literature that reflect real-life situations.

iv. ***Conducting a Literature Search.*** This is a topic that most students do not have experience in, since until now, textbooks and courses provide their primary source of information and knowledge. This course will educate the students on the importance and the place of literature search in research by carrying out activities to discuss the following:

- Significance of literature search in science research;
- Resources and search engines available through the Mt. SAC library;
- Popular search sites for research in chemistry;

- Conducting a literature search on a specific topic.

v. ***Introduction to Primary Science Literature.*** Most students have not come in contact with science journal articles in the past, and the few that have tried are probably intimidated by their level of complexity and use of technical terms. In this course, to teach students how to understand science articles and use them effectively, activities will involve:

- Distinguish between different types of literature publication;
- Critically read and analyze science journal articles; and
- Use the cited references in journal articles to obtain additional information.

vi. ***Nature of the Research Environment.*** To stimulate students' interest and enthusiasm for research, it is important to expose students to the various research environments and allow them to witness first-hand how research is conducted in different settings. Activities on this topic will consist of:

- Tour of academic research facilities; and
- Tour of industrial research facilities.

The purpose for both types of visits is to allow the students to observe, in different settings, how researchers work independently and their collaborative role in a research group, as well as being exposed to the use of advanced instrumentations in research.

vii. ***Research Opportunities.*** Once the students are interested in participating in research and are equipped with the basic knowledge of what research involves, they need to be aware of the research opportunities available to them. To accomplish this, the students will carry out the following activities:

- Conduct a search on summer research programs available to community colleges in nearby four-year institutions; and
- Conduct a search on research opportunities in four-year institutions that they would like to transfer to.

For both types of searches, the students will be required to find out specific information such as duration of the program, requirements, application process, etc. Due to time constraints, the students will be working in groups on these activities and they will have the option to choose which type of search they wish to conduct.

viii. ***Skills in Science Communication.*** Both written and oral communications skills are considered to be essential components of science research training. To expose students to how research results are often communicated in the scientific community and to train them in preparing their own presentation, activities will consists of:

- Attend a local research presentation conference; and
- Conduct research on a topic and make an oral PowerPoint presentation to the class.

Possible topics that students can prepare presentations for include recent articles in journals or search results on research opportunities. This would allow every student in the class to be fully aware of all the research opportunities open to them. To practice writing skills and to help students prepare for research opportunities, the students will be writing a statement of purpose (a requirement in the application process for summer research programs) on reasons why they wish to participate in research and its relevance to their major, academic career or future employment.

## Methods of Evaluation

Since this is not a traditional science course, then the usual methods of evaluations such as homework, quizzes, exams and final may not be the optimal tools to evaluate the students' progresses in this course. Instead, students will be evaluated on their level of comprehension on the course topics and mastery of the skills taught in the course. Specifically, the following criteria will be utilized to evaluate the students:

- Attendance and participation in class discussions;
- Successful completion of assignments for each course topic;
- Comprehension of class material as demonstrated by the level of accuracy and completeness in the finished assignments;
- Attendance and participation in research facility tours and research conference;
- Quality of the written work; and
- Quality of the oral presentation.

If time allows, students will have the opportunity to improve their grades on specific assignments by making the recommended changes or corrections. In this course, the main purpose of evaluating the students is to help them improve and not simply to penalize them for their mistakes. There will not be any formal exams or final in this course, since the scheduled assignments for each topic will serve as evaluation tools to gauge students' progresses.

## Course Assessment

For any new course, it is vital to the success of the course to conduct meaningful assessment at various stages to ensure that the goals and objectives of the course are being achieved, as well as to provide valuable information to refine the course. For this course, some of the assessment tools utilized in the exemplary classroom or non-laboratory research-related courses described in literature can be adapted here. To determine whether the students are really learning what the course is trying to teach, various assessment tool will be utilized at different stages of the course, including:

- Pre-course student attitude surveys, developed specifically for the course with questions on student perception of the course topics, to be conducted at the beginning of the semester;
- In-class assessment of student learning using ConcepTests and Minute Papers, occurring throughout the duration of the course;
- Mt. SAC's standard student evaluation (form H.2.a) of the course, to be conducted at the end of the semester;
- Post-course student attitude surveys, developed specifically for the course with questions on student perception of the course and their own learning, to be conducted at the end of the semester; and
- Post-course student assessment of learning gains, developed specifically for the course to identify elements in the course that best support student learning and those that need improvement.

In addition to these assessment tools, longitudinal tracking of students will also provide valuable insights on the success of the course, such as tracking how many students will apply to summer research programs, participate in research upon transferring, and graduate with their degrees in science. Collectively, the purpose of all the proposed assessment tools is to continuously improve the quality of the course to ensure the students are receiving the best education.

# PROJECT ACTIVITIES

***Part 3: Design of the 2nd Course – "Science Research Methodologies and Instrumentation"***

## COURSE GOALS AND PEDAGOGY

The first proposed course provides the basic foundation and training to introduce students to science research. However, as clearly reflected by the research results from part 1 (Research and Investigation on Research Training Courses) of this sabbatical project, much of science research also involve hands-on experimental skills, ability to analyze and correctly interpret data, problem-solving skills, and utilization of advanced instruments, as well as the capability to communicate research results via oral presentations and written reports. Thus, the goals of the second proposed research training course, "Science Research Methodologies and Instrumentation," are to engage students in various experimental research methodologies and provide hands-on training for common instrumentations utilized in research. Students will have opportunities to work independently as well as working together collaboratively as a team.

To achieve these goals, the pedagogical approach to the course is based on the valuable insights gained through the research and investigation process of this sabbatical project. Specifically, conclusions are drawn from the exemplary research-related courses found in literature (especially the laboratory courses), as well as from articles in literature that provide the current views on undergraduate research. Based on discussions presented in part 1 of this sabbatical report, a guided-inquiry, discovery-based approach will be adopted for this course. In this inductive learning approach, a question is posed at the beginning and the students carry out various activities to draw their own conclusions in answering the question. This approach induces students to exercise their critical thinking ability and increase their interest in the activity. In addition, when the students have to carefully analyze their data to find the correct answer based on their work (not one that is already pre-determined as in a traditional experiment), the experience simulates the research process.

In the literature, there are various categories of guided-inquiry, discovery based experiments and activities. For this course, three different types of guided-inquiry, discovery based approaches will be adopted:

- Solving an unknown;
- Solving the structure of an unanticipated product; and
- Determining trends from multiple data collection.

First, to achieve the goal of providing hands-on experience for common instrumentations in research, a series of guided-inquiry learning modules will be utilized to teach the students the fundamental theory concepts and basic operation techniques. Each learning module includes an unknown for the students to solve once they have demonstrated competency in using the instrument. To address the second goal of the course, additional guided-inquiry activities, similar in the form to short research-type projects, will be implemented. Consisting of multiple components that require students to carry out diverse activities and utilize several advanced instruments, these modules will expose students to various research methodologies and provide further hands-on experience on using instrumentation as an analytical tool. To further develop their communication skills in science, upon completion of these modules, students will prepare a written report and deliver an oral presentation on their results.

Being the second research training course, the pre-requisite for this course is the completion of the first course – "Introduction to Science Research." To allow students sufficient time to engage in the activities, this course would be appropriate as a two-unit course. Upon completion of both courses, the students should be adequately prepared to participate in research with confidence either in a summer program or at a four-year institution after transferring.

## Course Topics and Activities

To accomplish the goals of the course, a set of course topics and planned activities are selected. Again, the specific selection of the topics are guided by the patterns of similarity observed in the research-related course requirements in four-year institutions in California, and components of the exemplary laboratory research-related courses in the literature. The following discussion outlines the course topics and describes the planned activities for each topic.

i. ***Guided-inquiry learning modules.*** The first part of this course consists of learning modules that focus on the most common types of instrumentation utilized in research (as indicated by results summarized in part 1 of this sabbatical report), which include the following:

- Infrared spectroscopy (IR) for liquid and solid compounds;
- Proton- ($^{1}H$) and carbon-based ($^{13}C$) nuclear magnetic resonance spectroscopy (NMR) for liquid and solid compounds;
- Gas Chromatography (GC) for liquid and gas compounds;
- Gas Chromatography coupled with Mass Spectrometry (GC-MS) for liquid and gas compounds; and
- Molecular Modeling using Spartan software for structure optimization, energy calculations, and determination of molecular properties.

For each module, planned activities include introducing the students to the basic theory concepts, teaching them hands-on basic operation techniques, allowing students to practice with sample problems, and assigning each student an individual unknown to solve. Upon completion of each learning module, students are required to submit answers to the practice problems and a short written report on the identity of the unknown and their inductive reasoning for how the answer is obtained. In addition, adequate class time will be designated for students to discuss and share their results.

ii. ***Guided-inquiry student projects.*** The second part of the course topics comprises of additional guided-inquiry projects that are more complex and similar in nature to short research-type projects. The focus of these guided-inquiry projects involves either solving the structure of an unanticipated product or determining trends from multiple data collection. Topics for these projects vary from inorganic to organic, and do not require prior knowledge from the students. Planned activities for these projects include:

- Background material to introduce the topic and pose the question to the students;
- Experimental activities to collect data and observation;
- Utilization of several instruments to characterize the compounds;
- Collective analysis of all available observation, data and spectral characterization to determine the answer to the question;
- Class discussion of results and conclusion;
- Writing of a formal report for the project following the style of a journal article; and
- Preparation of a poster presentation to the class.

## METHODS OF EVALUATION

Similar to the first proposed course, this second course is also not a traditional science course, therefore, the usual methods of evaluations such as homework, quizzes, exams and final will not be utilized to evaluate the students' progresses in this course. Instead, students will be evaluated on their competency in operating the various instruments and level of comprehension on each learning module and project. Specifically, the following criteria will be utilized to evaluate and gauge the students' progresses:

- Attendance and participation in class discussions;
- Successful completion of each guided-inquiry learning module and project;
- Comprehension of class material as demonstrated by the level of accuracy and completeness in the finished practice problems;
- Demonstration of critical analysis of gathered data and reasonable logic to solve the unknown or provide a correct answer to the posed question;
- Quality of the written work, including both short reports and formal report; and
- Quality of the prepared poster and its oral presentation.

If time allows, students will have the opportunity to improve their grades by repeating certain experimental activities or instrumental analysis to gather more information to find their answer to the posed question. In this course, the main purpose of evaluating the students is to help them improve and learn from their mistakes, rather than just simply penalizing them for their mistakes. This concept is particularly important in a research training course, since in research, trial and error and repeated experimentation are common steps that often lead to productive results.

## COURSE ASSESSMENT

Being a new course, it is essential to conduct meaningful assessment at various stages to ensure that the goals of the course are being achieved, in addition to provide valuable information to refine the course in the future. Similar to the first course, to determine whether the students are really learning what the course is trying to teach, various assessment tool will be utilized at different stages of the course, including:

- Pre-course student attitude surveys, developed specifically for the course with questions on student perception of the course topics and instrumentation skills, to be conducted at the beginning of the semester;
- In-class assessment of student learning using ConcepTests, occurring throughout the duration of the course;
- In-class determination of students' abilities to apply specific procedural knowledge and skills using the performance assessment tool, occurring throughout the duration of the course;
- Peer evaluation of the poster presentation using the scoring rubics, to be conducted at the end of the semester;
- Mt. SAC's standard student evaluation (form H.2.a) of the course, to be conducted at the end of the semester;
- Post-course student attitude surveys, developed specifically for the course with questions on student perception of the course and their own learning, to be conducted at the end of the semester; and

- Post-course student assessment of learning gains, developed specifically for the course to identify modules or projects in the course that best support student learning and those that need improvement.

In addition to these assessment tools, longitudinal tracking of students that complete the course will also provide valuable insights on the success of the course. Collectively, the purpose of all the proposed assessment tools is to continuously improve the quality of the course to ensure the students are receiving the best education.

# Project Activities

*Part 4: Development of Course Materials*

## Overall Approach

After the designs of both courses are completed, the last step in this sabbatical project is to develop course materials that address the course goals, pedagogy and topics. The difficult challenge here is to generate course materials that are interesting and suitable for students with various backgrounds, since for the first course, the prerequisite is only the first semester of General Chemistry, which may lead to a class with students ranging from ones that just completed the prerequisite to those that are finishing the second year Organic Chemistry sequence.

As reflected by the results discussed in part 1 (Research and Investigation on Research Training Courses) of this sabbatical report, most four-year institutions do not offer any formal research training course. For the exemplary research-related courses described in literature, most of the course materials are developed by faculty or adopted from literature. Thus, there is no published textbook or lab manual available to adopt for both of the proposed courses here.

The approach to develop appropriate course materials is similar to those courses described in literature, where depending on relevancy, some of the material will be developed as part of the sabbatical project while others will be adopted and adapted from literature. This begins with a thorough literature search in the Journal of Chemical Education, utilizing the online search engine for all the issues as well as meticulously examining all the articles in issues from years 2000 – 2007 for relevant publications. The focus of the search is to find educational innovations, appropriate case studies, guided-inquiry activities, and discovery-based projects that have been published or cited in literature as successful practices. Specifically, key selection criteria include relevancy to the courses' goals and topics, as well as ability to stimulate student interest. Once the selection of journal articles is completed, then the actual activities are adopted and adapted to fit the course curriculum, with copyright permission obtained from the journal's editor. Portions of the adopted activities are modified to correspond to course goals and topics, as well as to the level of the students' background.

For the first course, majority of the course materials are created by assembling information from previous knowledge, dialogue with other faculty, online searches, and analysis of research results from part 1 of this sabbatical project. Specific case studies for a few course topics are adopted from literature. For the second course, most of guided-inquiry learning modules are combinations of created material and adopted activities from the literature, while all of the guided-inquiry student projects are adaptations of journal articles. For any material adopted from literature or online websites, proper reference are provided. The major advantage of utilizing activities from journal articles is that they have been tested and proven to be successful to use for classroom settings. In addition, these activities often represent the latest education innovations in chemical sciences.

## RESOURCES AND COURSE MATERIALS FOR THE 1ST COURSE

The resources and course materials for the first course – "Introduction to Science Research," are described in the following discussions, in the same order as the course topics presented in part 2 of this sabbatical report. For any material adopted from literature or online websites, a reference is provided here (rather than in a separate section).

i. ***Why Do Research.*** In-class informal discussions on this topic will focus on why is research an important component of applications to professional or graduate school, as well as the professional and personal benefits of a research experience. The following resources will serve as starting points for the discussions:

- Admission to U.S. Medical Schools. http://www.aamc.org/students/applying/about/start.htm (accessed June 2007)
- Lopatto, D. The Essential Features of Undergraduate Research. *Council on Undergraduate Research Quarterly* **2003**, *23*, 139-142.

ii. ***Introduction to Scientific Method.*** First part of the class discussion will focus on the "Inquiry Wheel" – an alternative description of the scientific method as it is utilized in science research (an article that students would read before coming to class). Class discussion will compare and contrast the differences between the "Inquiry Wheel" versus the traditional model that the students are familiar with. The second class activity consists of a guided-inquiry, discovery based hands-on case study of the scientific method, involving a reaction between Mentos and Diet Coke. Students will have a chance to work collaboratively and engage in all steps of the "Inquiry Wheel" to explain the reaction, including preparing a short written report and communicating their results to the class via a 5-minute oral presentation. The following resources are adopted and adapted for the two class activities:

- Robinson, W. R. The Inquiry Wheel, an Alternative to the Scientific Method. *J. Chem. Educ.* **2004**, *81*, 791-792.
- Eichler, J. F.; Patrick, H.; Harmon, B.; Coonce, J. Mentos and the Scientifc Method: A Sweet Combination. *J. Chem. Educ.* **2007**, *84*, 1120-1123.

For the hands-on case study, the students are given a separate handout, (instead of the original journal article that provided the class data), which is a modification of the original article to provide background information and any necessary instructions for the students to carry out the activity. *This handout for the case study is attached as part of Appendix B in this sabbatical report.*

iii. ***Ethics in Science Research.*** Before coming to class to discuss this topic, the students will be asked to read several articles from the literature:

- Borrego, A. M. 2 Scientists Who Worked in Harvard Professor's Lab Are Accused of Stealing Secrets. *The Chronicle of Higher Education* **2002**, *June 20.*
- Lanegran, K. Fending Off a Plagiarist. *The Chronicle of Higher Education* **2004**, *Jul 2*, A50.
- Barlett, T.; Smallwood, S. Four Academic Plagiarists You've Never Heard Of: How Many More Are Out There? *The Chronicle of Higher Education* **2004**, *Dec 17*, A51.

In-class discussions will focus on ethical challenges most frequently faced by undergraduate researchers such as assignment of credit, confidentiality, plagiarism, and fabrication or falsification of laboratory data. Following the discussions, students will examine, evaluate and discuss five ethical scenarios that correspond to those topics, adopted from literature:

- Mabrouk, P.A.; Peters, K. Student Perspectives on Undergraduate Research (UR) Experiences in Chemistry and Biology. *CUR Quarterly* **2000**, *21*, 25-33.

The students are given a separate handout on the five ethical case studies with discussion questions, instead of the original journal article which is too lengthy. *This handout for the case studies is attached as part of Appendix B in this sabbatical report.*

iv. ***Conducting a Literature Search.*** First portion of class discussions will focus on the significance and the role of literature search in science research, especially at the beginning of a research project. The students will first be introduced to the resources and search engines available at the Mt. SAC library via a scheduled session with a librarian. This activity will be followed by a handout distributed to the students on the common websites for literature search in Chemistry, along with sample problems for students to complete in class. *This handout on common websites is attached as part of Appendix B in this sabbatical report.*

v. ***Introduction to Primary Science Literature.*** Two recent articles, one from Science and the other from Journal of Organic Chemistry, will be distributed to students to read before coming to class. Topics will be selected from the most recent issues at the time when the course is offered. In-class discussion will first focus on the difference between the two articles, followed by detailed analysis of each article. Each article will be examined section by section, to teach the students how to extract useful information from journal articles, including useful references, even if they are not able to understand the entire article. In particular, students will work collaboratively in groups of 2-3 to answer a set of questions that pertain to a new journal article that they will receive at the end of the class discussion.

vi. ***Nature of the Research Environment.*** To stimulate students' interest and enthusiasm for research, tours of academic and industrial research facilities will be conducted as class field trips, as schedule permits. The following are some examples of tour sites and contacts:

- UCLA – Undergraduate Research Center, Center for Academic and Research Excellence; Laina Long, Bridge Program Coordinator, lainal@chem.ucla.edu, (310) 206-4600.
- UC Irvine – School of Biological Sciences; Outreach, Research Training and Minority Science Programs; Dr. Lidia Yoshida, Academic Coordinator, lyoshida@uci.edu, (949) 824-8185.
- Jet Propulsion Laboratory (JPL) – group tours offered through the Public Tours Office; (818) 354-9314; Open House during the third weekend in May.

All tours can be arranged in advanced for both Fall and Spring semesters, while the JPL Open House tour is only available during May of each year. Tours of academic research facilities will offer students insights on how research is conducted at universities (that they may transfer to), the interactions between undergraduate, graduate students and faculty, as well as the research facilities and advanced instrumentations. The JPL tour provides an overview of JPL's activities and accomplishments, in addition to visits to the Space Flight Operations Facility and the In-Situ Instruments Laboratory. The JPL Open House is unique since visitors will see exhibits, displays, demonstrations and presentations about new technologies, solar system exploration, spacecraft communication and much more. Many of the Lab's scientists and engineers will be on hand to answer questions about how spacecraft are sent to other planets, how scientists utilize space technologies to explore Earth and how researchers are now searching for planets beyond the solar system.

vii. ***Research Opportunities.*** To help the students become aware of the abundant research opportunities available to them and to sharpen their online search skills, the students will work in groups of 2-3 to conduct a search either on summer research programs for community college students or on research opportunities in four-year institutions for transferred students. Students will choose their activity depending on their current academic status and future plans for transfer. Both type of searches will be focused on schools in California, especially ones that are in close proximity to Mt. SAC and the popular transfer destinations for Mt. SAC students, including:

- UC Campuses – UCLA, UC Irvine, UC Riverside, UC Berkeley, UC San Diego, UC Santa Barbara;
- CSU Campuses – Cal Poly Pomona, CSU Fullerton, CSU Los Angeles, CSU San Bernardino, CSU Long Beach, CSU Northridge; and

- Independent/private institutions – USC, Chapman University.

Students will search the websites for the schools, identify the various research programs available (as detailed in part 1 of this sabbatical report) and summarize their findings to present to the class. In addition, for students that choose to focus on research opportunities for transferred students, they will select one of the faculty's research work that they are interested in and describe that research topic to the class.

viii. ***Skills in Science Communication.*** To expose students to how research results are often communicated in the scientific community, they will attend one of the local research conferences as a class field trip to observe how their peers conduct oral PowerPoint and poster presentations. Depending on whether it is the Fall or Spring semester, the following are appropriate conferences that showcase and celebrate undergraduate student research:

- Southern California Conference on Undergraduate Research (SCCUR) – a broadly multi-disciplinary, one-day conference that occurs in November of each year to provide a forum for the presentation and discussion of best research, scholarship, and creative work of undergraduates in the region.
- Undergraduate Research Symposium at UC Irvine – a one-day event to showcase undergraduate achievement in all disciplines, where more than 500 students present their research findings through oral and poster presentations to faculty, staff, members of UCI and general community.

Once the students have observed how professional presentations are conducted, then they will prepare and delivery their own PowerPoint presentation on the summarized findings on research opportunities to the class. In addition, to practice writing skills and to help students prepare for research opportunities, the students will be required to write a statement of purpose for one of the summer research programs or a short research proposal for one of the research-related courses at four-year institutions.

## Resources and Course Materials for the 2nd Course

The resources and course materials for the second course – "Science Research Methodologies and Instrumentation," are described in the following discussions, in the same order as the course topics presented in part 3 of this sabbatical report. For any material adopted from literature or online websites, a reference is provided on the handouts for the guided-inquiry learning modules or projects.

**Guided-Inquiry Learning Modules.**

The following describes the guided-inquiry learning modules that have been developed or adapted from literature for the following instruments:

- ***Nuclear Magnetic Resonance (NMR) Spectrometer.*** The first portion of this learning module consists of basic theory concepts, a sample preparation guide for liquid and solid compounds, and detailed operating instructions for obtaining various NMR spectra such as proton-based ($^{1}H$), proton-decoupled carbon-based ($^{13}C$), and distortionless enhanced polarization transfer carbon-based (DEPT $^{13}C$), in addition to advanced techniques such as block averaging with peak registration (BAPR) for collecting $^{13}C$ spectra of dilute solutions. The second part of the guided-inquiry learning module requires the students to collect both $^{1}H$ and $^{13}C$ spectra for an unknown, apply what they have learned to determine the identity of this unknown and explain their inductive reasoning. *Selected portions of this module are attached as part of Appendix C in this sabbatical report.*
- ***Infrared (IR) Spectrometer.*** The first portion of the learning module consists of basic theory concepts, a sample preparation guide, and operating instructions to obtain an IR spectrum. The second part of the guided-inquiry learning module

requires the students to apply what they have learned to collect an IR spectrum for an unknown, determine the identity of this unknown and explain their inductive reasoning. *Selected portions of this module are attached as part of Appendix C in this sabbatical report.*

- ***Gas Chromatographer coupled with Mass Spectrometer (GC-MS).*** This learning module introduces students to the theory and basic concepts of how a gas chromatographer and a mass spectrometer operate as well as their ability to separate and identify compounds. In addition, the students will be given an unknown that corresponds to group 6 transition-metal carbonyl compounds, where they can apply the GC-MS technique to determine the identity of the metal in the unknown by analyzing the fragmentation pattern and determining the atomic mass. *Selected portions of this module are attached as part of Appendix C in this sabbatical report.*
- ***Spartan software for Molecular Modeling.*** In this module, students will learn the basic commands, features and functions of the Spartan software through various activities. The purpose of these activities is to allow the students to: (1) comprehend the various types of calculations such as energy calculation, structure optimization, surfaces, and molecular properties, etc., (2) understand the different methods of calculations such as molecular mechanics, semi-empirical and ab initio Hartree-Fock molecular orbital, as well as the various options within each method, and (3) learn the role and utilization of molecular modeling in the science laboratory or research. Specific activities for this learning module will be adapted

from the "Tutorial and User's Guide" for Spartan (published by Wavefunction, Inc.).

**Guided-Inquiry Student Projects.**

The proposed guided-inquiry projects are more complex in nature than the guided-inquiry learning modules, and resemble short research-type projects in that they require the use of many analytical techniques as well as being more time consuming. The purpose of these projects is to allow the students to experience how various methodologies and instrumentations work together to solve a complex problem, such as solving the structure of an unanticipated product or determining trends from multiple data collection. In addition, the students will learn to communicate their results to the class via poster presentation. The following are the titles of the projects:

- Analysis of Air by Mass Spectrometry;
- Usnic Acid and the Intramolecular Hydrogen Bond; and
- Friedel-Crafts Acylation of an Unknown Compound.

*Detailed project descriptions are attached as part of Appendix C in this sabbatical report.*

# Conclusions

## Sabbatical Project Summary

I am extremely satisfied with the successful completion of my proposed sabbatical project, and deeply grateful to Mt. SAC for this wonderful opportunity to work on such an exciting project. As reflected by this sabbatical report, I take great pride in achieving the stated goal for this project – to research, design, and initiate the establishment of two research courses in the Chemistry Department at Mt. SAC. Each phase of the project has been completed with immense effort and meticulous attention to every detail to accomplish its intended purpose.

For phase I of the project, a comprehensive search and investigation on research training or research-related courses was conducted, focusing on four-year institutions in California, as well as on federal-funded research programs and successful practices on a national level. The research methods utilized for this phase include: (1) searching the catalogs of over 50 four-year institutions in California (10 UC campuses, 23 CSU campuses, 18 independent/private institutions that offer degrees in Chemistry) for research training or research-related courses; (2) navigating the funding opportunities from the National Science Foundation (NSF) and the National Institute of Health (NIH) for undergraduate research programs, especially ones open to community college students; (3) exploring relevant literature such as Journal of Chemical Education and publications from Council on Undergraduate Research for successful implementations of research components into the Chemistry curriculum; and (4) attending local and national conferences to dialogue with other faculty that have accomplished comparable tasks or share similar vision, as well as to learn about current innovations in chemical education.

*The collected data and analyzed findings from this research process are described thoroughly in part 1 of this report.*

The collective efforts from phase I serve as the solid foundation for phase II of the project, defining the various aspects that should be included in the two proposed courses. Specifically, the analyzed results are utilized to evaluate and determine the essential components for the two proposed courses in this sabbatical project (using the outlined topics in the sabbatical proposal as the template). In addition, the pedagogical approach to both courses is guided by the valuable insights gained through the research and investigation process, especially from the exemplary research-related courses found in literature as well as articles that provide the current views on undergraduate research.

Based on the abundance of research opportunities available to Mt. SAC students (as detailed in part 1 of this report), the first proposed course, "Introduction to Science Research," seeks to expose the students to the nature of research, stimulate their interest in science research, and properly prepare our students for these valuable experiences. The course goals, topics and activities are designed specifically to address the various research-related course prerequisites, course components or requirements, and research program selection criteria. *A comprehensive description of course goals, pedagogy, topics, activities, evaluation and assessment for the first proposed course is provided in part 2 of this sabbatical report.*

While the first proposed course provides the basic foundation and training to introduce students to science research, the second proposed course, "Science Research Methodologies and Instrumentation," engages students in various experimental research methodologies and provide hands-on training for common instrumentations utilized in research. The course goals, topics and activities are designed specifically to focus on the essential skills that students need for research (as defined in part 1 of this report), such as hands-on experimental skills, ability to analyze and correctly interpret data, problem-solving skills, and utilization of advanced instruments, as well as the capability to communicate research results via oral presentations and written reports. Based on discussions presented in part 1 of this sabbatical report, a guided-inquiry, discovery-based approach is adopted for this course. This approach simulates the research process, where students are induced to exercise their critical thinking ability and increase their interest in the activity. *A comprehensive description of course goals, pedagogy, topics, activities, evaluation and assessment for the second proposed course is provided in part 3 of this sabbatical report.*

Phase III of the sabbatical project consists of developing course materials for the two proposed courses, based on the course goals, topics and activities defined in parts 2 and 3 of this report. For the first course, majority of the course materials are created by assembling information from previous knowledge, dialogue with other faculty, online searches, and analysis of research results from part 1 of this sabbatical project. Specific case studies for a few course topics are adopted from literature. For the second course, most of guided-inquiry learning modules are combinations of created material and adopted activities from the literature, while all of the guided-inquiry student projects are adaptations of journal articles. *Part 4 of this report describes the resources and developed course materials for both courses in detail, while representative samples are attached as appendices B and C.*

# VALUE OF THE SABBATICAL PROJECT TO THE COLLEGE

## Professional Enrichment and Growth

As an educator, my professional goal and passion in life are to contribute excellence to science education and to provide exceptional learning experience to students. This sabbatical project has provided the enormous opportunity for me to learn the best practices from the successful implementations nationwide, dialogue with experts in the field, and gain the vital knowledge necessary to create quality science training courses at Mt. SAC. The scope of the finished project pleasantly exceeded my initial expectation and planning (as outlined in the original sabbatical proposal); moreover, the entire duration of the sabbatical leave has been an exciting, enriching and rewarding learning experience. I am deeply grateful that this project has allowed me to gain expertise in an area that I strongly believe will shape the future direction of science education. I look forward to the coming academic year with a refreshed, invigorated attitude and an eagerness to contribute to the instructional program at Mt. SAC.

## Benefits to the Students, Chemistry Department and College

The greatest benefit of this sabbatical project to the students is the excellent quality education that they will receive by incorporating science research training courses into the curriculum at Mt. SAC. These courses will provide the rare opportunity for students to learn the various aspects of research; discover research opportunities both before and after transfer; gain important research skills; think and work like a scientist; develop professional communication skills; increase self-confidence as an independent learner/researcher; and achieve proficiency in the application of modern analytical instrumentation. In addition, the completion of these courses would equip our students with knowledge and confidence to seek research opportunities, as well as enhance their preparation for transfer to four-year institutions. More importantly, these courses would enable all interested students to participate, not just a few elite, top notch students.

The Chemistry Department continuously provides a quality instructional program that utilizes the latest technology and innovation for lecture delivery and laboratory instruction. This sabbatical project follows the Chemistry Department's commitment to excellence philosophy and directly benefits the Department by complementing and expanding the current Chemistry curriculum to provide students with exceptional learning opportunities. Upon completion of the majors sequence of chemistry courses and the two proposed courses, students would have acquired multiple exposures and hands-on experience to state-of-the-art instruments in the Department, a valuable asset for their upper-division courses, research activities, or future industry employment. In addition, the proposed courses have the potential to boost students' interest in Chemistry and encourage them to pursue it as a major or a career. Indirectly, the enrollment for Chem 99 (Independent Study/Projects) may increase, since students completing the two courses may choose to continue their projects in Chem 99. Furthermore, this sabbatical project report contributes to Chemistry Department's and Mt. SAC's knowledge base in providing other faculty with the resources to teach these or other similar courses.

On a broader level, this sabbatical project is directly correlated to and promotes Mt. SAC's mission and vision statements. *To provide accessible and affordable quality learning opportunities*, this project makes science research training available to all interested students, by incorporating the training as courses into the curriculum. *To provide quality transfer, career, and life-long learning programs,* the two proposed courses would provide the students with important knowledge and essential skills to be more successful in transitioning to other institutions, academic research, industrial positions and future careers. *To advance the state's and region's economic growth and global competitiveness,* implementation of science research training into the curriculum can potentially increase the number of science graduates, resulting in a larger scientific, technical and engineering workforce for our society. To strive as *one of the premier community colleges in the nation* and *a leader in community college teaching,* successful implementation of science training into the curriculum at Mt. SAC would serve as a national model for other community colleges and elevate Mt. SAC's prestige.

**Future Endeavors**

During the sabbatical leave, Iraj Nejad (faculty in the Chemistry Department) and I prepared and submitted a five-year grant proposal to the Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program at the National Science Foundation (NSF). This grant proposal, entitled "Mt. SAC Scholars Program," has been awarded by NSF and funded for $597,540 effective from October 1, 2007 to September 30, 2012. *The project summary of the grant proposal is attached as appendix D in this sabbatical report.* Through this grant project, a scholarship program will be established to recruit and support academically talented, financially needy students and enable them to attain higher education degrees in STEM disciplines. A minimum of 37 *academic scholarships* for a maximum of $2,700 per scholarship and 10 *research scholarships* for a maximum of $3,000 per scholarship will be awarded annually. Research scholarships will provide invaluable opportunities for selected scholarship recipients to engage in authentic research at partnering four-year institutions during the summer. The two proposed courses in this sabbatical project will effectively prepare students in the scholarship program for the summer research experience.

# APPENDIX A

## Sabbatical Leave Proposal

(November 2006)

# Introduction of Science Research Training Into the Curriculum

Sabbatical Project Proposal

2006-2007

Jenny S. Chen

Chemistry Department

## Abstract

Research at the undergraduate level is widely recognized as a powerful pedagogical tool that significantly enhances the quality of undergraduate science education. Many studies suggest that undergraduate research plays a pivotal role in science students' success to graduation and their choice to pursue careers in sciences. This sabbatical project proposes an innovative, novel approach to effectively provide such exceptional learning experience to the general student population, by incorporating research into the curriculum through the development of two science research training courses. Through this sabbatical project, Dr. Chen would be able to learn the best practices from the successful implementations nationwide, dialogue with experts in the field, gain the vital knowledge necessary to create quality science training courses at Mt. SAC, build the foundation to offer these courses and provide excellent learning opportunities to all interested students.

## INTRODUCTION

Research at the undergraduate level is widely recognized as a powerful pedagogical tool that significantly enhances the quality of undergraduate science education. Many studies suggest that undergraduate research plays a pivotal role in science students' success to graduation and their choice to pursue careers in sciences. This success appears to be centered on the research involvement and the mentorship that students experience by working closely with faculty members and peers in all learning situations.

Although the experience is invaluable, science research opportunities at the undergraduate level are limited to juniors or seniors, and typically engage only a relatively small number of advanced students. At Mt. SAC, only a few students each year participate in summer research, offered by programs at neighboring universities, four-year colleges and research institutions (such as UCLA, Cal State Fullerton, Jet Propulsion Laboratory, etc.). Most of these summer research programs invite applications from all community colleges; therefore, the competition is fierce and only the top notch, most academically accomplished, highly qualified science students get selected.

Mt. SAC presents both a wonderful opportunity and a unique challenge in terms of being able to provide quality science research training and experiences to our students. The vast opportunity emanates from the fact that enrollments in Science, Technology, Engineering and Mathematics (STEM) courses in two-year colleges account for nearly one-third of the total enrollment in these courses nationwide, according to data reported by the National Science Foundation (NSF). Mt. SAC, being a premier community college and the largest single campus in California, possesses the potential to positively impact a large number of STEM students and serve as a national model for other community colleges. The difficult challenge is the reality that, the number of research opportunities and access to research facilities available to Mt. SAC students are limited. In addition, community college students often have to work, making it nearly impossible for them to pursue additional educational opportunities such as science research.

An innovative, novel approach to effectively provide quality science research training to the broad student population, not just the few elites, is imperative.

## Project Overview and Goals

The goal of my sabbatical project is to research, design, and initiate the establishment of two research courses – "Introduction to Science Research" and "Science Research Methodologies and Instrumentation" – in the Chemistry Department at Mt. San Antonio College. These courses would serve as gateway courses to prepare students for research projects on campus, summer research opportunities at other institutions, research at their transfer institutions, or future careers in science.

The first course, "Introduction to Science Research," presents a brief overview to what science research involves. Its primary role is to attract students to learn about science research and stimulate their interests to pursue research further. The second course, "Science Research Methodologies and Instrumentation," provides a more in-depth exposure to discovery-based learning and hands-on training for various instruments frequently utilized in science research. In both courses, students would have opportunities to complete independent projects of their choice and communicate their results in a professional presentation.

The greatest benefit of incorporating science research training into the curriculum at Mt. SAC is the excellent quality education students will receive. These courses will provide the rare opportunity for students to think and work like a scientist, improve problem-solving skills, develop professional communication skills, enhance teamwork skills, increase self-confidence as an independent learner/researcher, and gain proficiency in the use of scientific tools and instrumentation. More importantly, these courses would enable all interested students to participate, not just a few elite, top notch students.

## Project Activities, Timeline & Expected Outcomes

**Phase I: Research and Investigation.**

To design courses that focus on community college students, adopt the best practices in teaching pedagogy, and incorporate the elements of cutting-edge sciences, the first crucial step is a comprehensive search and investigation on similar courses offered at other institutions. Currently, most colleges and universities do not offer a formal training course in science research; each research program or faculty mentor provides the basic information and much of the training is informal with the students learning as they proceed with the research.

The main components of the comprehensive research and investigation process are *data collection* and *compilation of data.* Proposed project activities, timeline and expected outcomes (goals) are described in the following table.

| **Month** | **Week** | **Proposed Project Activities** | **Expected Outcomes/Goals** |
|---|---|---|---|
| August | 4th | Consult Chemistry, Biology, and Psychology Department faculty to obtain input. | Identify the important topics and available instruments. |
| September | 1st<br>2nd<br>3rd<br>4th | Search the catalogs of all California colleges and universities for similar course offerings and examine their course content.<br>• all 9 University of California campuses<br>• all 20 California State University campuses<br>• other private universities and four-year colleges | Locate all similar courses in these potential transfer schools (most Mt. SAC students transfer to California schools).<br><br>Create a course that is most beneficial and advantageous to our students. |
| October | 1st<br>2nd | Search the major funding agency websites to investigate which institutions have received funding in recent years to create such courses or programs, and examine their course content.<br>• National Science Foundation<br>• National Institute of Health<br>• Other national funding agencies | Seek out similar courses or programs on a national level. |
| October<br><br>November | 3rd<br>4th<br>1st | Search relevant journals for prototypes or case studies on science research implementation into the curriculum, such as:<br>• Council on Undergraduate Research<br>• Journal of Chemical Education<br><br>Attend local, national conferences. | Identify all successful cases of science research implementation into the curriculum. |

| | | | |
|---|---|---|---|
| November | 2nd<br><br>3rd | Contact and dialogue with specific faculty or personnel at respective institutions that represent:<br>• Public universities<br>• Private colleges/universities<br>• Community colleges | Learn about the best practices to adopt and pitfalls to avoid. |
| November<br><br>December | 4th<br><br>1st | Compile the collected data on all research training courses. | Summarize the findings. |

**Phase II: Designing the Two Courses.**

Current planning and initial conception of the core components for the two courses are outlined here. The first course, designed to attract students to science research and expose them to exciting real world applications of science, would be appropriate as a one-unit course with the following components.

1st Course: Introduction to Science Research

- Scientific method – introduction and case study
- Tour of academic research facilities (e.g. UCLA, Cal State Fullerton, JPL, etc.)
- Attend a research conference that showcases student presentations (e.g. Southern California Conference on Undergraduate Research, American Chemical Society Conference, etc.)
- Tour of industrial research facilities (e.g. Sunkist Company, Miller Brewing Company, etc.)
- Literature/online search on a topic of student interest
- Professional presentation on the researched topic

The second course, "Science Research Methodologies and Instrumentation," engages the students in a more in-depth study of discovery-based learning/methods and provides hands-on training for common instrumentations utilized in science research. This course would be appropriate as a two-unit course, with the following components.

2nd Course: Science Research Methodologies and Instrumentation

- A complete case study from discovery, hypothesis, design, experimentation, instrumentation, analysis to conclusion.
- Series of Learning Modules; each module includes basic theory concepts, operation instructions and guided-inquiry, open-ended components, to teach discovery-based learning/methodologies and hands-on training for instruments.

- Research type project – students will choose topic, hypothesize, design, test and refine experimental procedures, collect and analyze data, draw conclusions.
- Professional presentation of the research type project.
- Write a short scientific report on their research type project ***OR*** write a short research proposal suitable for continuation of research project in Chem 99 (Independent Study) ***OR*** prepare application materials for summer research opportunities.

Upon completion of Phase I, Research and Investigation (data collection and compilation process), *the compiled data will be analyzed to draw conclusions.* Results will then be utilized to evaluate, assess and determine the essential components for the two courses, using the above outlined topics as the template. Modifications based on the analyzed data, including any additions or deletions of topics, will be made accordingly to complement and supplement this initial template. Proposed project activities, timeline and expected outcomes (goals) are described in the following table.

| Month | Week | Proposed Project Activities | Expected Outcomes/Goals |
|---|---|---|---|
| December | 2nd<br><br>3rd | Analyze the collected and compiled data to draw conclusions, specifically focusing on the following aspects:<br>• Selection of course topics<br>• Breadth and depth of topics<br>• Elements aimed at generating student interest<br>• Selection of experiments or modules<br>• Criteria for student project topics selection<br>• Appropriate level of difficulty for student projects<br>• Choice of instruments utilized in teaching & student projects<br>• Criteria for professional oral and poster presentations<br>• Criteria for written reports<br>• Methods of evaluation | Identify the patterns of similarities and differences.<br><br>Select the key components and topics in the research training courses.<br><br>Determine the appropriate length of time and depth on each topic. |
| December<br><br>February | 4th<br>to<br>3rd | Enjoy the winter break; reflect and meditate on the progress of the sabbatical project. | Return with refreshed attitude, valuable insights, and more inspiration. |

| | | | |
|---|---|---|---|
| February<br><br>March | 4th<br><br>1st<br><br>2nd<br><br>3rd | Prepare, write and edit portions of the sabbatical report detailing the process for Phases I and II. | Provide a current review of similar science training courses.<br><br>Describe the key components and topics in the research training courses.<br><br>Delineate the course outline for the two courses.<br><br>Define course goals and measurable objectives for the two courses.<br><br>Develop guidelines for and methods of evaluation. |

**Phase III: Creating and Developing Course Materials.**

Upon final selection of course topics, determination of course goals and definition of measurable objectives, the remainder of the sabbatical project will be focused on creating the course content and developing course materials for the two courses. This is the most difficult stage of the sabbatical project to define, since it is challenging to predict at this point, which exact components will constitute the two courses.

The following table will illustrate the approach to development of course materials and define the type of activities proposed for major components in the two courses. *This is only an estimated projection/example, as modifications (and possible additions or deletions) will be made accordingly, once Phases I and II are completed.*

| Month | Week | Proposed Project Activities | Expected Outcomes/Goals |
|---|---|---|---|
| March<br><br>April | 4th<br><br>1st | Contact appropriate personnel to set up academic and industrial research facilities tours.<br>• Confirm possible dates & times<br>• Identify responsible parties<br>• Finalize type of activities<br>• Obtain any necessary permission or paperwork | Offer various tours for students to select from.<br><br>Provide opportunities for students to view cutting-edge science in action, using state-of-the-art facilities and instrumentations. |

| | | | |
|---|---|---|---|
| April | 2nd<br><br>3rd<br><br>4th | Identify possible topics for student literature/web search and research type projects.<br>• Search through relevant journals in Chemistry and Biology<br>• Adopt and adapt topics used in similar courses<br><br>Prepare an information packet for the possible topics (for instructors). | Provide a comprehensive list, addressing the major topics and latest trends or breakthroughs in science, for students to choose or obtain ideas from.<br><br>Be able to offer valuable help to students in a timely manner. |
| May | 1st<br><br>2nd<br><br>3rd<br><br>4th<br><br>5th | Select, adapt or write, and test specific modules to teach discovery-based methodologies and hands-on training of instruments.<br>• Introduction to the instrument's capability and application<br>• Simple experiment to demonstrate the instrument's basic operation<br>• Guided inquiry experiment to assess unknowns<br>• Open-ended questions for students to draw conclusions<br><br>Selection process will utilize information from relevant journals and similar courses. | Present a complete module for each of the frequently utilized instrumentations in science research, such as Infrared (IR) Spectroscopy, Nuclear Magnetic Resonance (NMR) Spectroscopy, Spartan Molecular Modeling software, Gas Chromatography (GC), Ultraviolet-Visible Spectrophotometry, etc. |
| June | 1st<br><br>2nd | Prepare, write and edit portions of the sabbatical report detailing the process for Phase III. | Summarize the developed course materials for both courses. |

Although the course contents are not well defined yet, the approach to development of course materials for any modifications will be similar to what is described above. The eventual and long-term goal, after completion of the sabbatical project, is to develop a comprehensive instructor's resource manual for each of the two courses, to facilitate other faculty in the Chemistry Department in teaching these courses. In addition, these resource manuals would also allow other faculty at Mt. SAC or elsewhere to adopt and adapt to teach similar courses in their own department.

## Merit/Value & Benefit of the Sabbatical Project

### Professional Enrichment and Growth

As an educator, my professional goal and passion in life are to contribute excellence to science education and to provide exceptional learning experience to students. This sabbatical project will provide the enormous opportunity for me to gain expertise in an area that I strongly believe will shape the future direction of science education.

In the past five years, I have been the liaison between Mt. SAC and UCLA Center of Academic Research and Excellence. I actively recruit, select and advise students to participate in the four-day DNA Workshop and the ten-week summer research program at UCLA. In the past summer, through a NSF-funded grant (titled "Planning Forward to Create an Undergraduate Research Center at a Community College"), my colleague Iraj Nejad and I were able to recruit, select, interview, mentor and fund eight Mt. SAC students to conduct ten weeks of summer research at UCLA, Cal State Fullerton and Cal State LA. We also assisted the students in preparing professional presentations, via oral and poster as well as written reports, on their research results. The students successfully and proudly presented their research at the conclusion of the summer program at their respectively institutions, Mt. SAC Conference Day (October 28, 2005) and Southern California Conference on Undergraduate Research (November 19, 2005).

I have thoroughly enjoyed working closely with the students in the past years and witnessed first-hand the transformation, growth, maturity, self-confidence and inspiration that result from students' participation in research. Through this sabbatical project, I would be able to learn the best practices from the successful implementations nationwide, dialogue with experts in the field, gain the vital knowledge necessary to create quality science training courses at Mt. SAC, build the foundation to offer these courses and provide exceptional learning opportunities to all interested students, not just a few elites.

### Benefits to the Department

In the past years, to continuously enhance the quality of education to our students, the Chemistry Department has introduced a new course for Allied Health majors, modified a course to better prepare students for General Chemistry, implemented Calculator-Based Laboratory technology into General Chemistry courses, incorporated

Spartan Molecular Modeling into both General and Organic Chemistry courses, developed the Chemistry Technician Program, and submitted three proposals to the National Science Foundation (NSF), all successfully funded.

The Chemistry Department provides a quality instructional program that utilizes the latest technology and innovation for lecture delivery and laboratory instruction. This sabbatical project follows the Department's commitment to excellence philosophy and directly benefits the Chemistry Department (and Mt. SAC) in the following ways:

- Complement the existing Chemistry curriculum by providing students with excellent training and experiences in science research.
- Utilize the current state-of-the-art instruments in the Department, such as Nuclear Magnetic Resonance (NMR) spectrometer and Gas Chromatograph – Mass Spectrometer (GC-MS), to provide valuable hands-on experience for our students.
- Offer multiple exposures to instrumentation for our students, an important tool in science research, when they complete their Chemistry courses.
- Expand students' interest in Chemistry (or the sciences) and encourage them to pursue sciences.
- Increase the enrollment for Chem 99 (Independent Study/Projects), since students completing the two courses may continue their projects in Chem 99.
- Equip our students with knowledge and confidence to seek research opportunities.
- Enhance our students' preparation for transfer.
- Contribute to Chemistry Department's and Mt. SAC's knowledge base.
- Provide Chemistry and other faculty with the resources to teach these courses.

**Benefits to the College**

The proposed activities are directly correlated to and promote Mt. SAC's mission and vision statements.

- *To provide accessible and affordable quality learning opportunities*, this project seeks to make science research training to be available to all interested students, by incorporating the training as courses into the curriculum. Even at universities and four-year colleges, only a relatively small number of students are able to learn and participate in research.

- *To provide quality transfer, career, and life-long learning programs,* the two proposed courses would provide the students with important knowledge and essential skills to be more successful in transitioning to other institutions, academic research, industrial positions and future careers.

- *To advance the state's and region's economic growth and global competitiveness,* implementation of science research training into the curriculum can potentially increase the number of science graduates, resulting in a larger scientific, technical and engineering workforce for our nation.

  Our world and society are changing constantly, large in part due to rapid advances in science and technology. The economy is shifting from industrial base to knowledge-based enterprises, where highly educated and skilled workers are increasingly important and in high demand.

  As university and private college tuitions continue to escalate, community colleges will eventually become the foundational source of quality education for majority of students. Consequently, systematic change in community college curriculum that can significantly enhance the quality of education would greatly benefit our society.

- The innovative approach presented in this sabbatical project to increase student participation and success in science research promotes Mt. SAC's vision – to strive as *one of the premier community colleges in the nation* and *a leader in community college teaching,*

  Successful implementation of science training into the curriculum at Mt. SAC would serve as a national model for other community colleges and teaching institutions.

# APPENDIX B

Case Studies for the 1st Course

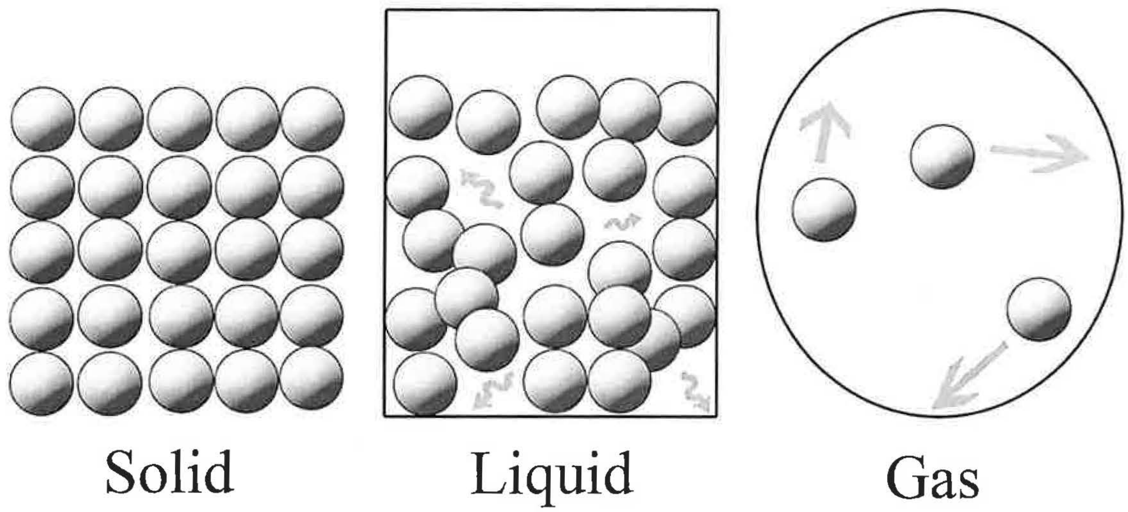
"Introduction to Science Research"

# MENTOS AND THE SCIENTIFIC METHOD – A CASE STUDY

Reference: Eichler, J. F.; Patrick, H.; Harmon, B.; Coonce, J. Mentos and the Scientifc Method: A Sweet Combination. *J. Chem. Educ.* **2007**, *84*, 1120-1123.

## GENERAL BACKGROUND:

The three primary states of matter are solids, liquids, and gases.




**Solids.** The molecules in a solid are vibrating, but they held very tightly together and are kept in fixed positions. They are very difficult to compress and are unable to flow. Thus, they have a constant shape and volume. When a solid is heated, the molecules move faster, and they are able to break away from the rigid solid structure.

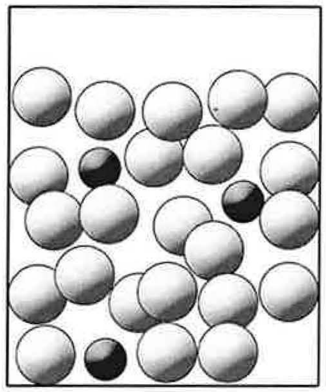
Some solids can be dissolved into some liquids. Whether or not a solid is soluble in the liquid depends on the properties of the substances, the temperature, and the solution concentration. When a solid is completely dissolved in a liquid, the solution will become transparent.

**Liquids**. The molecules in a liquid are still fairly close together, but they are able to move freely . The volume of a liquid is constant, but its shape changes to fit the container.

**Gases**. The molecules in a gas are very far apart and move at very high speeds. Gases fill the volume and shape of the container in which they are placed.

Gases can also be dissolved into a liquid. When a gas is completely dissolved in a liquid, you won't be able to see bubbles. (Observe the soda bottle before you open it.) To dissolve a gas in a liquid, just bubble the gas through the liquid. The gas molecules will be "caught" by the liquid molecules!

More gas can be dissolved in a liquid under high pressures and low temperatures. This is why a soda can is kept pressurized and cold. If left open and warm, the dissolved carbon dioxide gas will leave, and the soda becomes "flat."



Liquid with dissolved gas

## INSTRUCTOR DEMONSTRATION:

The instructor will quickly submerge 16 mint Mentos (predrilled and strung onto a thin wire) into a freshly opened 2-liter bottle of Diet Coke. You will document all of the experimental conditions and record accurate observations, including:

- The approximate temperature of the Diet Coke;
- The approximate height of the fountain;
- The approximate volume of the Diet Coke left in the bottle; and
- The appearance of the Mentos after the experiment.

## FORMING A HYPOTHESIS:

**How are bubbles formed in a reaction?**

1. **A physical reaction.** Dissolved gas simply separates from the solution as bubbles. You can observe this type of reaction by shaking a soda can and then opening it.

2. **Chemical reaction.** The chemicals combine to form a gas.
You can observe this reaction by placing an antacid into orange juice. When the antacid neutralizes the acidic orange juice, carbon dioxide gas is formed.

In groups of 2-3 students, discuss what took place and come up with a hypothesis explaining why the fountain had occurred. Is this a physical or chemical reaction or both? What specific factors are responsible for the reaction?

## EXPERIMENTAL DESIGN:

Once the hypothesis is formed, then design your own experiments to test your hypothesis.

**Procedural Advice:**

1. In order to save on materials, you will test your hypothesis by doing a series of experiments where you use 1 mentos and place it in a 16-20 oz. bottle of the specified beverage.

2. You will be given a measuring stick to determine how vigorous each "reaction" is.

3. Each group should do 2 trials (for each experiment) in order to provide some assurance that the experiments are repeatable.

4. Be sure to document all experimental parameters and results in your lab notebook.

5. The data from all the groups in your lab section will be compiled in order to help determine the precision of the experimental procedures. You should then calculate the standard deviation for each experiment:

Standard Deviation (SD) = $\sqrt{[(1/n)(\text{sum } (x_i - x_{avg})^2)]}$
n = number of data points
$x_i$ = individual data points
$x_{avg}$ = mean of data points = sum $x_i$ / n

The standard deviation should be reported to the same number of decimal places (not significant digits) as the average value. Thus, if you calculate the SD to be 0.0026 and your average value is 2.225, you should report this data as 2.225 +/- 0.003.

## DATA ANALYSIS AND CONCLUSIONS:

1. Which experiments confirmed your hypothesis? Which disproved your hypothesis? Be sure to explain why each experiment confirmed/disproved your hypothesis.

2. Based on your standard deviations, are you confident that all of your experimental results are trustworthy?

3. Based on the analysis of your results, would you modify your hypothesis? How?

**REPORT WRITING**:

For each group, prepare a short report with the following components:

- Copies of the lab notebook sheets;
- A summary of the data;
- Sample calculations (for the mean and standard deviation of the height of the fountain and for the volume of beverage remaining);
- An analysis explaining whether the hypothesis was confirmed or denied; and
- Any proposed modification to the original hypothesis.

Upon completion of the report, each group will present their final conclusions to the class via a 5-minute oral presentation.

# Ethical Dilemmas Most Frequently Encountered By Undergraduate Research Students

Reference: Mabrouk, P.A.; Peters, K. Student Perspectives on Undergraduate Research (UR) Experiences in Chemistry and Biology. *CUR Quarterly* **2000**, *21*, 25-33.

**Assignment of Credit** – not being given credit for intellectual contributions to the research project

**Confidentiality** – ideas in the research lab shouldn't be discussed outside the lab without the principal investigator's permission

**Plagiarism** – words are intellectual property, i.e., we own the expression of our ideas on paper (copyright)

**Fabrication/falsification of data** – fabrication is the action of making up data; falsification is the action of altering data

## Case Study 1: Pinocchio's Nose

Tom, a pre-med. student, works two part-time jobs while attending Prestigious University. Tom finds his course load for the spring semester very challenging and he struggles to keep up with the assignments in his anthropology course. Tom knows anthropology instructor, Dr. B., thinks highly of him and that Dr. B has a reputation of being somewhat of a softy when it comes to "good" students. So, having missed the deadline for submission of an important paper, Tom goes to Dr. B with the story that he and his twin brother were in a serious car accident over the weekend. Tom explains that he didn't hand in the assignment because he has been at the hospital sitting at his brother's bedside in ICU where his brother is now on life support. Dr. B is of course very sympathetic and grants Tom an extension on the assignment. Later in the semester Tom once again finds himself behind the eight ball on an assignment...

As a group, discuss each of the following questions:

1) What should Tom do?

2) If Tom weren't a pre-med. student and didn't work two part-time jobs, would this affect your evaluation of the situation?

## Case Study 2: The Cost of Integrity

Dr. X, a distinguished structural engineer, received a phone call from an engineering student at a nearby college. The student expressed concern that Dr. X's famous skyscraper had a serious technical design flaw. At first, Dr. X dismissed the student's concerns outright but the conversation gets him thinking. Over the weekend, Dr. X sifts through his data and realizes the student is indeed correct – strong winds could cause this famous landmark to topple and in the process kill thousands of innocent people. Rectifying the problem would be no small task and would require notifying the building's owners, city officials, and the press and might negatively impact Dr. X's professional reputation.

As a group, discuss each of the following questions:

1) What should Dr. X do?

2) Dr. X could lose his career if he admits the error. Geographically, the building is located in a region where there is a very low risk of high winds. Should either of these issues influence Dr. X's decision about what to do next? Why/why not?

## Case Study 3: "Borrowing" Without Permission

Lisa, a postdoctoral student in Prof. X's lab is told that she will not be re-appointed when her current 1-year contract expires. Lisa feels that Prof. X has the funds to support her but that he simply doesn't like her and that is why he is not reappointing her. Angry with Prof. X and determined to get back at him, Lisa decides that she will take her lab notebooks, some lab supplies, and several critical laboratory reagents when she leaves. Lisa is surprised a month later when armed policemen show up at her parents' home to arrest her...

As a group discuss each of the following questions:

1) Do you think that Lisa should be arrested for what she did?

2) Could Lisa's actions impact anyone else in the lab where she worked? Do you think this exacerbates or ameliorates the gravity of her offense?

3) Would your opinion of the situation change if Lisa were a high school student who got an idea for a science fair project while working in Prof. X's lab and wants to carry out her own research?

### Case Study 4: It's All About Sharing…

Xian, a summer high school research student at Big University, was flattered when a graduate student, Pingwei, at another university e-mailed him inquiring about his research. Since Xian had just finished writing a progress report for his research advisor, Xian sends it as an attachment with his e-mail. Over the next few months, Pingwei e-mails Xian several additional times asking very specific questions about the project which Xian happily answers. A few months later, Xian is surprised to see Pingwei's name on the by-line of a technical article in a leading scientific journal. Xian is even more surprised when he reads the article and sees text, figures and tables that were clearly taken word-for-word from ***Xian's*** progress report.

As a group discuss each of the following questions:

1) What should Xian do?

2) Do you think that Xian could/should have done anything differently?

**Case Study 5: Copy and Paste…**

Late in the afternoon, Lisa finally had a chance to google for information on "problem-based learning" for her course assignment due the next morning. Though she was tired, she couldn't help but wonder when she noticed that the text published on the first two websites she found was almost identical word-for-word. Both websites were for education courses being taught by two different faculty at two different academic institutions. Curious, she emailed the authors of both papers concerning her observation and printed out a copy of both pages to bring with her to class the next morning.
As a group discuss each of the following questions:

1) Has Lisa found an example of plagiarism?

2) In your opinion is this a serious issue? Would you change your opinion if the two sources were instead peer-reviewed papers which had been published in respected education journals?

3) Does Lisa have any ethical obligation to notify the academic institutions involved of the similarity of the information published on the two course websites? Again, would your conclusion be different if the sources were peer-reviewed, published technical articles?

# Websites for Literature Search

CRC: Handbook of Chemistry and Physics, 87th ed., 2006-2007

http://www.hbcpnetbase.com/

Merck Index Online

http://library.dialog.com/bluesheets/html/bl0304.html

Chemfinder.com: Database and Internet Searching

http://chemfinder.cambridgesoft.com/

Sigma-Aldrich

http://www.sigmaaldrich.com/Area_of_Interest/The_Americas/United_States.html

Spectral Database for Organic Compounds SDBS

http://www.aist.go.jp/RIODB/SDBS/cgi-bin/cre_index.cgi

NIST Chemistry WebBook

http://webbook.nist.gov/chemistry/

SciFinder Scholar

http://www.cas.org/SCIFINDER/SCHOLAR/index.html

CrossFire Beilstein

http://www.mdl.com/products/knowledge/crossfire_beilstein/

# Appendix C

Guided-Inquiry Modules and Projects for the $2^{nd}$ Course

"Science Research Methodologies and Instrumentation"

# NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY

Reference: Glagovich, N. M.; Shine, T. D. Organic Spectroscopy Laboratory: Utilizing IR and NMR in the Identification of an Unknown Substance. *J. Chem. Educ.* **2005**, *82*, 1382-1384.

**OBJECTIVE:** To learn about Nuclear Magnetic Resonance (NMR) and its use as a tool for characterization of compounds. To learn about functional groups in organic molecules. To apply what you have learned in class about molecular structure and bonding.

**MATERIALS:**
60 MHz FT-NMR instrument
Samples of selected chemicals
Unknown samples
Molecular models

**SAFETY:** Samples used in this experiment all contain organic compounds. Sample tubes are capped and should remain capped throughout the experiment. Vapors of organic solvents can be dangerous over prolonged exposure to them.

## Introduction

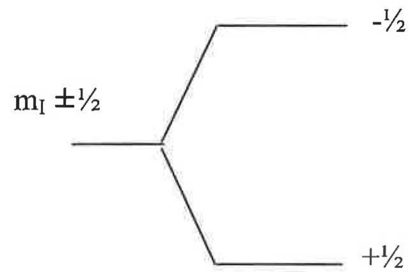
In order to identify the chemical formula and structure of molecules, chemists often use spectroscopic techniques to characterize molecules. **Spectroscopy** is defined as an experimental process in which the energy differences between allowed states of a system are measured by determining the frequency of the light absorbed. This energy is determined by the expression:

$$E = h\nu$$

where h is equal to Planck's constant and ν is the frequency usually measured in Hz ($s^{-1}$). Depending on the frequency and the type of transition studied we have different spectroscopic techniques such as atomic absorption spectroscopy, ultraviolet spectroscopy (uv), infrared spectroscopy and nuclear magnetic resonance spectroscopy (NMR) among the most common ones. Each technique offers information about different electronic or nuclear transitions in a molecule. The combined information from spectroscopic techniques allows you to obtain a good picture of the structure of a molecule. What does this spectroscopic information look like? Well for each form of spectroscopy there is an instrument involved that generates a **spectrum** that you as the researcher can "read" and interpret. A spectrum is a graph with signals that correspond to the different electronic or nuclear transitions.

## Nuclear Magnetic Resonance

In this experiment we will be using the technique of nuclear magnetic resonance (NMR) to identify simple organic molecules. How does this technique work? Protons and neutrons in the nucleus of an element can be assigned a magnetic quantum spin number (I) with a value of ½. If the spin of all protons and neutrons in a nucleus pair up (comparable to when electrons pair up in orbitals) there is no net nuclear spin and the net value of I is I=0. When the net value of I equals ½ then we say that this unpaired spin gives the nucleus a magnetic moment. In human terms this means that when the nucleus of this element is exposed to a magnetic field the protons align with respect to the magnetic field creating two energy states with values of $m_I$ equal to +½ or – ½. The number $m_I$ is called the nuclear spin angular quantum number.

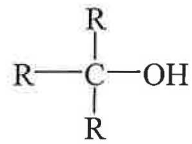



NMR studies the transition from one state to the other. The energy difference between the two states corresponds to radio frequency radiation. Common isotopes that are studied through NMR are $^{1}H$, $^{13}C$ and $^{31}P$. In this experiment we will be looking at $^{1}H$ and $^{13}C$ spectra. Hydrogen and carbon nuclei in molecules will allow the value of $m_I$ to go from +½ to -½ at different frequencies depending on the environment (the atoms bonded) around them. This behavior is called **resonance** and it is the basis for characterizing molecules through NMR.

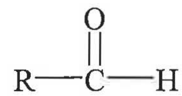
## Functional Groups

Certain bonded combinations of elements have very characteristic and consistent properties. These groupings are called **functional groups**. In today's experiment we will be looking at four different types of oxygen containing functional groups:

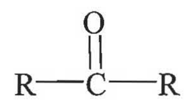
Alcohols



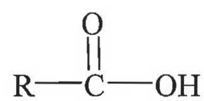
Aldehydes



Ketones



Carboxylic Acids



R = C or H

The chemical properties of these types of compounds are very different from each other. They also display very distinct signals in an NMR spectrum.

**Interpreting NMR Data**

How do we put all of this information together and make some sense out of NMR spectra? Let's start with an example. Let's say we take the $^1H$ and $^{13}C$ NMR spectra of the molecule $CH_4$. This molecule has 4 hydrogen atoms but all of them are chemically equivalent to each other. The $^1H$ NMR spectrum of this molecule would show a single signal to indicate the presence of hydrogen atoms chemically equivalent to each other and not interacting with anything else. The $^{13}C$ would also show 1 signal to account for only one type of carbon.

Let's try a more complex molecule such as the one below:

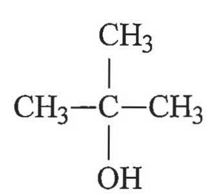
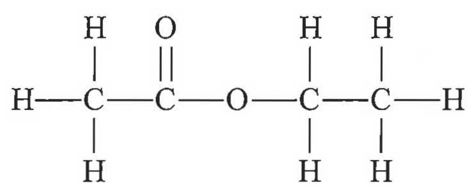


Figure number 1 shows the spectrum for this molecule. Let's identify the different hydrogen environments in this molecule. There are two different hydrogen environments. One is that of the nine hydrogens attached to the three carbon atoms that are attached to the central carbon atom. The other one is the environment of the hydrogen attached to oxygen. The spectrum shows a sharp signal at 1.236 ppm and another one at 4.565 ppm. These values account for the two different environments. The unit of ppm (parts per million) represents a ratio of the frequencies used in the experiment and is referred to as the **chemical shift**. Which peak belongs to which set of hydrogens? Usually anything attached to a highly electronegative element will appear at a larger chemical shift value, thus the peak at 4.565 ppm corresponds to the hydrogen attached to the O-H group of the molecule. How many signals would you expect to see in the $^{13}C$ spectrum of this molecule?

You will also notice the lines drawn over each peak with values of 1.35 and 9.00 respectively. These lines are called **integrals** and represent the number of hydrogens in each environment. You can actually measure these lines and establish a ratio of the hydrogens present in the molecule.

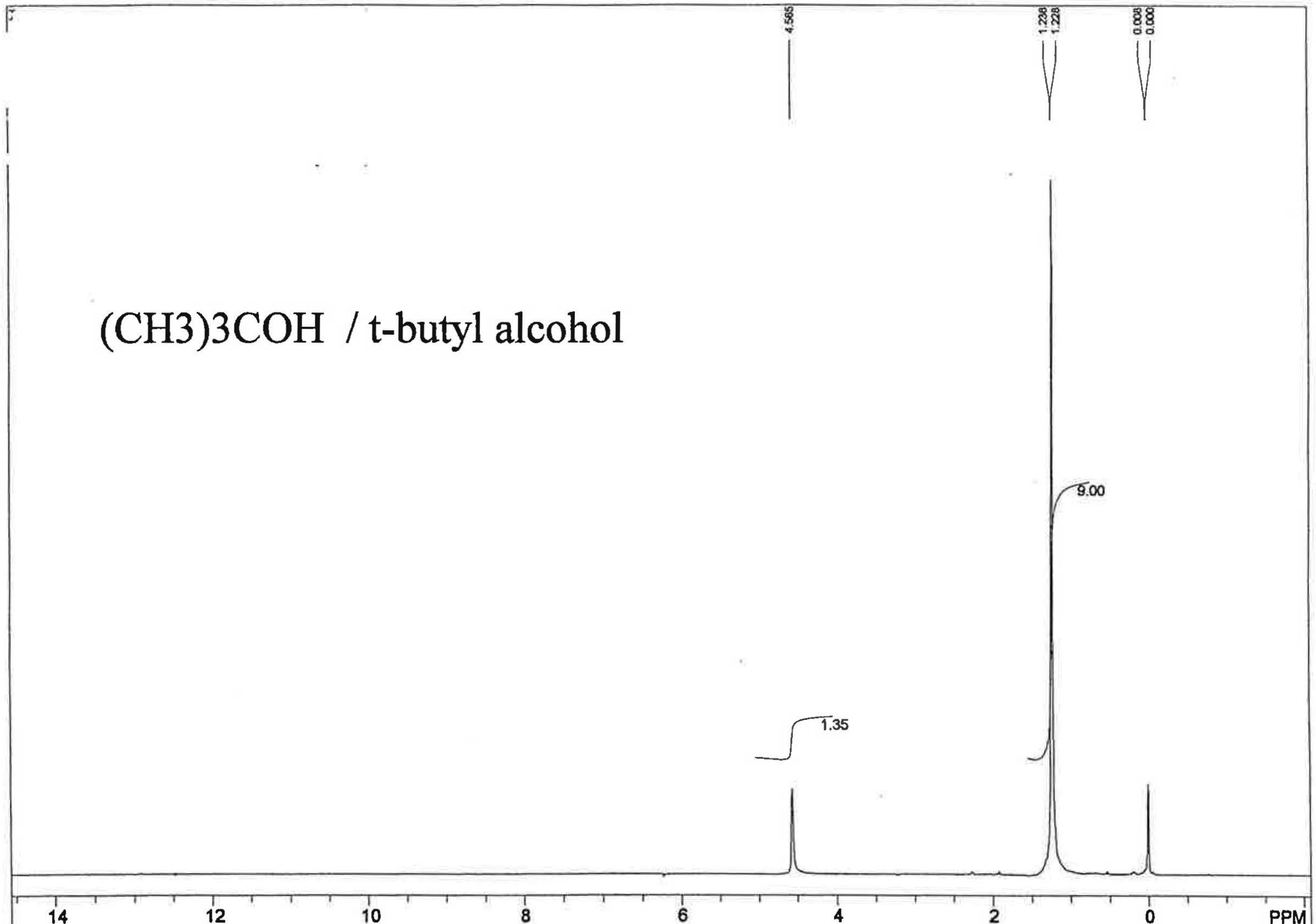
Let's try another structure:



How many different hydrogen environments are present in this molecule?

Three. One for the hydrogens on the $CH_3$ group on the left, the second one for the $CH_2$ hydrogens and the third one for the $CH_3$ group on the right.

Figure 1




USER: rdavila -- DATE: 1-24-01

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| F1: 60.010 | | SW1: 1000 | | OF1: 374.3 | | PTSld: 8192 | |
| EX: t-butyl alcohol | | PW: 0.0 usec | PD: 0.0 sec | NA: 1 | LB: 0.0 | | WinNuts - data |

We would expect three different regions of signals. But that is not the only thing we will see in this molecules' spectrum! Actually, when groups of different hydrogens are close to each other they affect each other's environment. This is what happens between the $CH_2$ and the $CH_3$ groups that are next to each other:

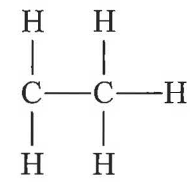
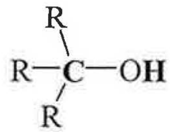
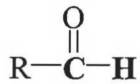
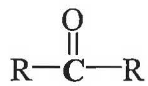
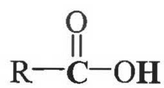


Figure 2 shows the spectrum for the whole molecule. We see a single peak at 2.028 ppm. This would agree with the $CH_3$ on the left side of the molecule. Then we see a set of 4 peaks at around 4.000 ppm. This set corresponds to the $CH_2$ group. Why do we see four peaks? Here we apply the **n + 1 rule**. The hydrogens in the $CH_2$ group are influenced by the three hydrogens on the $CH_3$ group. The signal we see is the value of n for the number of hydrogens affecting the $CH_2$ + 1 or in other words, n + 1 = **3+ 1** = **4**. How many peaks would we see for the $CH_3$ signal? Two hydrogens affecting the $CH_3$ plus 1 or n+1 = **2+ 1** = **3.** You can see the three peaks between 1.350 and 1.370 ppm.

Most spectra are referenced at 0.00 ppm. This value is assigned to tetramethylsilane, a compound added to NMR samples to set the NMR scale. This is the small peak you see at 0.00 ppm on the spectrum.

## NMR Spectra And Functional Groups

Functional groups involving hydrogen and carbon display very distinct signals and chemical shifts in both $^1H$ and $^{13}C$ NMR spectra. We will concentrate on the functional groups that we will use as unknowns in this experiment. The table below shows the common chemical shifts for the different signals for each functional group:

| | | $^{1}$H Chemical Shift | $^{13}$C Chemical Shift |
|---|---|---|---|
| Alcohols |  | 0.5-5.5 ppm | 50-60 ppm |
| Aldehydes |  | 9.5-10.0 ppm | 190-200 ppm |
| Ketones |  | | 205-220 ppm |
| Carboxylic Acids |  | 10.0-13.0 ppm | 177-185 ppm |

R = other C or H groups

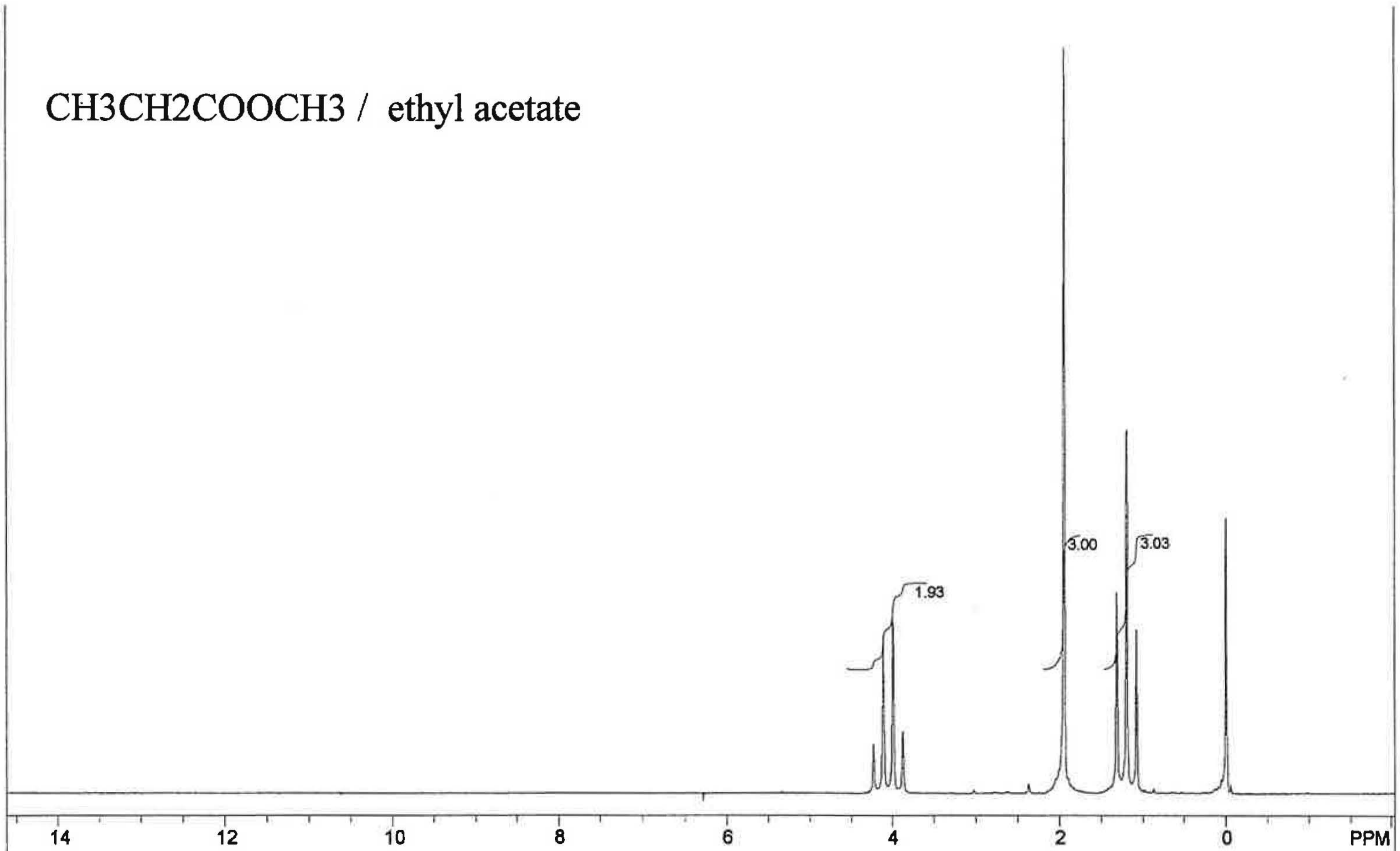



Figure 2

USER: rdavila -- DATE: 1-24-01

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| F1: 60.010 | | SW1: 1000 | | OF1: 377.2 | | PTS1d: 8192 | |
| EX: ethyl acetate | | PW: 0.0 usec | PD: 0.0 sec | NA: 1 | LB: 0.0 | | WinNuts - data |

# NMR SAMPLE PREPARATION GUIDE

**For all samples:**

- Use a total volume of ***0.7 mL*** (or ***4 cm***) liquid height.
- If the sample contains solid particles, then filter the solution through glass wool or cotton that is loosely packed in a Pasteur pipette.
- Use Wilmad 507-pp or equivalent quality sample tubes.
- Use a clean pipet for every transfer. Do NOT contaminate the $CDCl_3$ or TMS.

**For $^{1}H$ samples:**

**A minimum sample concentration of about **5 %** (or **0.3 M**) is generally appropriate.*

1. Use a clean pipet or clean spatula to add your sample. (For solids, if solubility is a concern, then you may need to weigh the exact amount of solid first.)
2. Use a clean pipet to add enough $CDCl_3$ (with 1 % TMS) solvent so that the total volume is ***0.7 mL*** or ***4 cm*** in height in the NMR tube.
3. Tab the NMR tube gently to mix the contents. Cap the NMR tube.

**For $^{13}C$ samples (liquid compounds):**

**A neat liquid sample (100 % concentration) is appropriate and will give good spectra in 1 minute.*

1. Use a clean pipet to add enough of your sample to reach ***0.7 mL*** or ***4 cm*** in volume height in the NMR tube.
2. Use a clean pipet to add one drop of TMS to the NMR tube.
3. Tab the NMR tube gently to mix the contents. Cap the NMR tube.

**For $^{13}C$ samples (solid compounds):**

**For solid samples, make the sample as concentrated as possible. For a 1 M sample, a good spectrum can be obtained in about 5 minutes (or 200 scans).*

1. In a clean test tube or small vial, dissolve as much solid as you can in as little $CDCl_3$ solvent as possible. If possible, calculate the exact amounts in advance.
2. Use a clean pipet to add enough of the solution mixture to reach ***0.7 mL*** or ***4 cm*** in volume height in the NMR tube.
3. Cap the NMR tube.

## STEPS TO PUT THE NMR SAMPLE IN

1. Open the cover.
2. Turn the "***spinner switch***" off (up = off, down = on) and push the "***air flow***" button to get the previous sample out of the probe.
3. Place your sample in the sample spinner and make sure that it is at the right height by inserting it in the depth gauge (at the front of the instrument).
4. Push the "***air flow***" button to start the air flow (to avoid breaking the NMR tube inside the instrument). As you drop the sample in the probe, <u>slowly</u> release the "***air flow***" button.
5. Turn the "***spinner switch***" on and make sure your sample is spinning (you can use the flashlight to check).

   **A NMR tube that is not spinning will give poor spectra with very broad peaks.*
6. Close the cover.

## $^1$H NMR Data Acquisition (PNMR) & Processing (NUTS)

1. In the PNMR program, if the prompt is not "**H1**", then type "nu h1" and press "**enter**".
2. Type "zg" and press "**enter**" to start data collection. Enter a file name for your sample and click "**save**".
   (A grey window will appear in the upper right hand corner of the screen.)
3. If the signal is yellow in color, then when data collection is complete, the grey window will disappear.
   (If a red signal appears on the screen, then you will be asked to lower the receiver gain. To do this, type in "rg 10", press "**enter**", followed by typing "zg".)
4. Use the mouse button to click the tab for the "NUTS" program (at the bottom of the screen).
5. Press "**Ctrl**" and "**F2**" keys at the same time. Select your file to open.
   (This will bring up a window where you can type your name, date & sample unknown number. Once you've entered this information, click "**Ok**". A picture of your spectrum will appear on the screen.)
6. Make sure the TMS signal appears at 0 ppm. If not, ask your instructor to show you how to set up the reference.
7. Type "zo". This will take you to the zoom routine to focus on the specific ppm region of the peaks.
   Using the mouse, place the cursor to the left of the most downfield peak and, while pressing the left mouse button down, select the area over the peak. Release the mouse button and press the number "**1**" key. Select a second region in the same way for the most upfield peak and press the number "**2**" key. Press "**enter**" upon completion.
8. Type "pe". This will allow you to phase the peaks on the spectrum to make the peaks appear symmetric.
   While pressing the left mouse button, move the mouse from left to right until the baseline on each side of the peak is the same height (the peak should look

symmetrical). Repeat this process but pressing the right mouse button this time. Press "**enter**" upon completion.

9. Type "fb". This will allow you to fit the baseline to make the baseline appear even and flat.

   A series of red stripes will appear on the baseline area If a red stripe is on the peak or is too close to the peak, then click on the stripe (using the mouse button) to remove it. Press the letter "**l**" for Least Squares fit for the baseline. Press "**enter**" upon completion.

10. Type "id". This will allow you to display the integrals and make adjustments to them.

    - To control the height of the integral lines, scroll the bar on the left side of the screen (using the mouse button).
    - To obtain individual integral values for each peak, use the mouse to place the cursor on the left side of the farthest left peak and click the left mouse button twice. Place the cursor on the right side of the peak and click the left mouse button once. This will select the integral for that peak. Repeat the same procedure for all the peaks in your spectrum except for TMS.
    - Optional: To assign a specific integral value, place the cursor on the vertical portion of the integral and click the left mouse button once. Type "**v**" and enter a number for that integral. This will automatically change all other integral values based on this.
    - Press "**enter**" upon completion.

11. Press "**Ctrl**" and "**I**" keys at the same time to display the integrals you selected.
12. Type "pp" to automatically pick peaks for you and give you their chemical shift.
13. To select the region for printing, type "zo" and use the mouse button to select the region to print (highlighted in red). Press "**enter**" upon completion.
14. Press "**Ctrl**" and "**E**" keys at the same time to display the expanded region you selected.
15. Type "pl" to obtain a plot of your spectrum.

## $^{13}C$ NMR Data Acquisition (PNMR) & Processing (Nuts)

1. In the PNMR program, if the prompt is not "**C13**", then type "nu c13" and press "**enter**".
   This will switch the parameters to carbon-13 data collection parameters. For neat samples, the standard 12 scans will be appropriate. For less concentrated samples, change the number of scans to 60 by typing "ns 60". For very diluted samples, 200 scans may be required.
2. Type "zg" and press "**enter**" to start data collection. Enter a file name for your sample and click "**save**".
   (A grey window will appear in the upper right hand corner of the screen.)
3. When data collection is complete, the grey window will disappear.
4. Use the mouse button to click the tab for the "NUTS" program (at the bottom of the screen).
5. Press "**Ctrl**" and "**F3**" keys at the same time. Select your file to open. Enter "0.5" for the line broadening (LB) value.
   (This will bring up a window where you can type your name, date & sample unknown number. Once you've entered this information, click "**Ok**". A picture of your spectrum will appear on the screen.)
6. Type "pp" to automatically pick peaks for you and give you their chemical shift.
   *Press "**Ctrl**" and "**B**" keys at the same time to display or hide the table.
7. Type "pl" to obtain a plot of your spectrum.

# $^{13}$C DEPT Data Acquisition (PNMR) & Processing (NUTS)

8. In the PNMR program, if the prompt is not "**C13**", then type "nu c13" and press "**enter**".

   This will switch the parameters to carbon-13 data collection parameters.

   _Optional_: Type "shim" and press "**enter**"to optimize the parameters. On-screen directions will request you to enter a relaxation delay (RD) value. For dilute sample, RD = 5 and for concentrated sample, RD = 2. Allow time for the shimming process to complete.

9. Type "zgh" and press "**enter**" to start to collect data for a $^1$H spectrum.
10. Use the mouse button to click the tab for the "NUTS" program (at the bottom of the screen).
11. Type "a2" to process the $^1$H spectrum. Use the mouse to place the cursor on the TMS peak to determine its position in ppm, including sign.
12. To enter the TMS peak position, use the mouse button to click the tab for the "PNMR" program (at the bottom of the screen).

    Type "fo" and the first dialog box will appear. Type in the current position (in ppm and with sign) of the TMS peak and press "**enter**". A second dialog box will appear, type "0.00" for the desired position of the TMS peak and press "**enter**".

13. Verify the parameters for the DEPT program. For neat samples, the standard 12 scans will be appropriate. For less concentrated samples, change the number of scans to 60 by typing "ns 60". For very diluted samples, 200 scans may be required.
14. Run the DEPT program by typing "dept" and press "**enter**".
15. Type in a filename and press "**enter**" OR just press "**enter**" to use the default filename My_dept.
16. Upon completion of data collection for DEPT 45, DEPT 90 and DEPT 135, use the mouse button to click the tab for the "NUTS" program.
17. To process the data, press "**Ctrl**" and "**F11**" keys at the same time. Select your file to open. Enter "0.5" for the line broadening (LB) value.

18. A stacked plot of the DEPT 135 (top), 90 (middle) and 45 (bottom) will be displayed. Adjust the amplitude with Page Up/Page Down, arrow keys or vertical slider on screen.
19. Type "p" to print the stacked plot of DEPT spectra.
20. To exit stacked plot display and show the $^{13}C$ spectrum only, press "**enter**".
21. To redisplay the stacked plot of DEPT spectra, type "sp".

## $^{13}C$ DEPT INTERPRETATION GUIDE

| | C | CH | $CH_2$ | $CH_3$ |
|---|---|---|---|---|
| DEPT 45 | 0 | ↑ | ↑ | ↑ |
| DEPT 90 | 0 | ↑ | 0 | 0 |
| DEPT 135 | 0 | ↑ | ↓ | ↑ |

Depending on the type of carbon, its signal in the various DEPT spectrum will be displayed as either up, down OR not be displayed.

## Block Averaging with Peak Registration Guide (BAPR)

1. In the PNMR program, if the prompt is not "**C13**", then type "nu c13" and press "**enter**". This will switch the parameters to carbon-13 data collection parameters.
2. Type "shim" and press "**enter**"to optimize the parameters. On-screen directions will request you to enter a relaxation delay (RD) value. For dilute sample, RD = 5 and for concentrated sample, RD = 2. Allow time for the shimming process to complete.
3. Type "zgh" and press "**enter**" to start to collect data for a $^1$H spectrum.
4. Use the mouse button to click the tab for the "NUTS" program (at the bottom of the screen).
5. Type "a2" to process the $^1$H spectrum. Use the mouse to place the cursor on the TMS peak to determine its position in ppm, including sign.
6. To enter the TMS peak position, use the mouse button to click the tab for the "PNMR" program (at the bottom of the screen).

   Type "fo" and the first dialog box will appear. Type in the current position (in ppm and with sign) of the TMS peak and press "**enter**". A second dialog box will appear, type "0.00" for the desired position of the TMS peak and press "**enter**".

7. Verify the parameters for the BAPR program. Choose 60 scans (ns) per block by typing "ns 60". For very diluted samples, more scans may be required to see the peaks after one block.
8. Run the BAPR program by typing "bapr" and press "**enter**".
9. Type in a filename and press "**enter**".
10. Type in the number of blocks to collect data and allow the spectrometer to shim between blocks.
11. Upon completion of data collection, use the mouse button to click the tab for the "NUTS" program.
12. Type "lb" and enter "1.0" for the line broadening (LB) value.
13. To process the first spectrum, type "a3" and select your file to open.

14. To define the registration peak, type "zo" to zoom to an isolated peak (that is well separated from other peaks) and type "0" to define the zoom region.
    Note: The zoom region must contain only one peak.

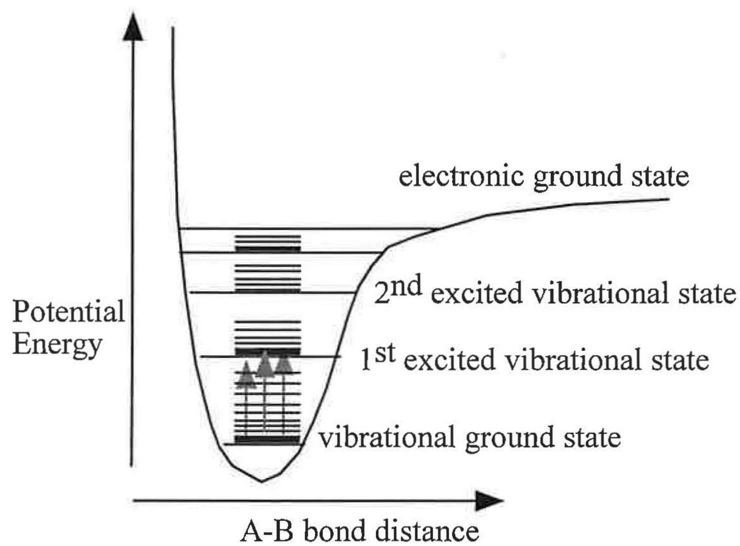
15. To run bapr processing which sums all the blocks, press **"Ctrl"** and **"F12"** keys at the same time. Select your file to open and a $^{13}C$ spectrum will be displayed.
16. Type "pl" to obtain a plot of your spectrum.

# INFRARED SPECTROSCOPY

Reference: Clough, S. C.; Kanters, R. P.; Goldman, E. W. Chem 111: A General Education Course in Organic Structure Determination. *J. Chem. Educ.* **2004**, *81*, 834-836.

## INTRODUCTION

**Infrared spectroscopy** (**IR**) is an analytical technique that provides information regarding the presence or absence of particular functional groups in a molecule. A typical infrared spectrum is very characteristic of a given sample and can serve as a fingerprint of a compound such that if the spectrum of an unknown and an authentic sample match, there is a strong likelihood that the sample and the unknown are the same.




Molecules are always in motion. These motions include **translations**, **rotations**, and **vibrations**. All these motions have discrete energy levels associated with them (so-called quantized energy levels). When an appropriate amount of energy is supplied to a molecule, excitation of molecules from a lower to a higher vibrational energy level can occur. This energy typically falls in the infrared region of the electromagnetic spectrum. Thus we say that vibrational excitation is involved in infrared spectroscopy. In the picture to the right, one sees that each vibrational state has a number of rotational states. In gases the rotational state energies can sometimes be resolved, giving rise to a set of closely spaced absorptions with energies close to the vibrational excitation energy,

Unlike UV-Vis spectroscopy, where the energy differences are reported in wavelengths (usually in nanometers), the unit used to report the energy of vibrational excitations is called a **wavenumber** and is expressed in **cm$^{-1}$**. This is the reciprocal of the wavelength expressed in centimeters. You might recall that frequency is inversely proportional to wavelength so the wavenumber is essentially a frequency unit: the higher the wavenumber, the higher the energy. The symbol used for it is the ν, like frequencies, with a bar over it: $\bar{\nu}$

$$\bar{\nu} = \frac{1}{\lambda}$$

The frequency of the vibration is related to the mass of the atoms and the force constant of the bond holding the atoms together. **Hooke's Law** does an adequate job of describing the frequency of these vibrations:

$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}}$$

where k is the force constant of the bond, and $\mu$ is the reduced mass of the atoms. The reduced mass of a system depends on the geometry, but for a two atom system it is the product of the masses divided by the sum:

$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

Hooke's law suggests that bonds involving small atoms like hydrogen should absorb at higher frequencies, whereas bonds connecting heavier atoms like carbon and oxygen should absorb at relatively lower frequencies. Similarly multiple bonds, being stronger than single bonds, should also absorb at higher frequencies.

| | | | |
|---|---|---|---|
| O-H | 3300 $cm^{-1}$ | C≡C | 2100 $cm^{-1}$ |
| N-H | 3400 $cm^{-1}$ | C=C | 1650 $cm^{-1}$ |
| C-H | 3000 $cm^{-1}$ | C-C | 1000 $cm^{-1}$ |

## TYPES OF VIBRATIONS

There are two types of vibrations possible: **stretching** vibrations and **bending** vibrations. Since it takes more energy to stretch a bond than it does to merely bend it, the bending vibrations occur at significantly lower frequencies.

| **Stretches** | | **Bends** | |
|---|---|---|---|
| vibration | Typical wavenumber | vibration | Typical wavenumber |
| O-H str | 3300 $cm^{-1}$ | O-H bend | 1500-1300 $cm^{-1}$ |
| N-H str | 3400 $cm^{-1}$ | N-H bend | 1600-1400 $cm^{-1}$ |
| C-H str | 3000 $cm^{-1}$ | C-H bend | 1480-1370 $cm^{-1}$ |

The result is that the IR spectrum can be considered to have two regions. From about 1600 to 4000 $cm^{-1}$ the spectrum is rather easy to interpret. The **stretching** vibrations of the many functional groups are easily assigned, so this can be considered the diagnostic region of the spectrum. This is where we will devote most of our attention.

From about 400 to 1600 $cm^{-1}$ the spectrum is more difficult (although not impossible) to interpret. All **bending** vibrations along with the **C-O**, **C-C**, **C-S** and **C-C stretches** fall in this region and overlap one another to the extent that assignments are less straight-forward. Note that the spectrum in this region, as complicated as it might be, is still the result of vibrations that are specific to the particular sample and thus provide a good fingerprint of the sample.

## CHARITERISTIC IR ABSORPTION OF FUNCTIONAL GROUPS

| **Functional Group** | **Molecular Motion** | **Wavenumber ($cm^{-1}$)** |
|---|---|---|
| alkanes | C-H stretch | 2950-2800 |
| | $CH_2$ bend | ~1465 |
| | $CH_3$ bend | ~1375 |
| | $CH_2$ bend (4 or more) | ~720 |
| alkenes | =CH stretch | 3100-3010 |
| | C=C stretch (isolated) | 1690-1630 |
| | C=C stretch (conjugated) | 1640-1610 |
| | C-H in-plane bend | 1430-1290 |
| | C-H bend (monosubstituted) | ~990 & ~910 |
| | C-H bend (disubstituted - E) | ~970 |
| | C-H bend (disubstituted - 1,1) | ~890 |
| | C-H bend (disubstituted - Z) | ~700 |
| | C-H bend (trisubstituted) | ~815 |
| alkynes | acetylenic C-H stretch | ~3300 |
| | C,C triple bond stretch | ~2150 |
| | acetylenic C-H bend | 650-600 |
| aromatics | C-H stretch | 3020-3000 |
| | C=C stretch | ~1600 & ~1475 |
| | C-H bend (mono) | 770-730 & 715-685 |
| | C-H bend (ortho) | 770-735 |

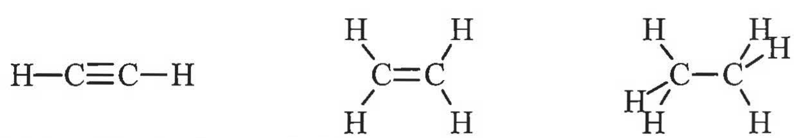
| | | |
|---|---|---|
| | C-H bend (meta) | ~880 & ~780 & ~690 |
| | C-H bend (para) | 850-800 |
| alcohols | O-H stretch | ~3650 or 3400-3300 |
| | C-O stretch | 1260-1000 |
| ethers | C-O-C stretch (dialkyl) | 1300-1000 |
| | C-O-C stretch (diaryl) | ~1250 & ~1120 |
| aldehydes | C-H aldehyde stretch | ~2850 & ~2750 |
| | C=O stretch | ~1725 |

| | | |
|---|---|---|
| ketones | C=O stretch | ~1715 |
| | C-C stretch | 1300-1100 |
| carboxylic acids | O-H stretch | 3400-2400 |
| | C=O stretch | 1730-1700 |
| | C-O stretch | 1320-1210 |
| | O-H bend | 1440-1400 |
| esters | C=O stretch | 1750-1735 |
| | $CH_3$-C(O)-OC stretch (acetates) | 1260-1230 |
| | C-C(O)-OC stretch (all others) | 1210-1160 |
| acid chlorides | C=O stretch | 1810-1775 |
| | C-Cl stretch | 730-550 |
| anhydrides | C=O stretch | 1830-1800&1775-1740 |
| | C-O stretch | 1300-900 |
| amines | N-H stretch (1 per N-H bond) | 3500-3300 |
| | N-H bend | 1640-1500 |
| | C-N Stretch (alkyl) | 1200-1025 |
| | C-N Stretch (aryl) | 1360-1250 |
| | N-H bend (oop) | ~800 |
| amides | N-H stretch | 3500-3180 |

| | | |
|---|---|---|
| | C=O stretch | 1680-1630 |
| | N-H bend | 1640-1550 |
| | N-H bend (1°) | 1570-1515 |
| alkyl halides | C-F stretch | 1400-1000 |
| | C-Cl stretch | 785-540 |
| | C-Br stretch | 650-510 |
| | C-I stretch | 600-485 |
| nitriles | C,N triple bond stretch | ~2250 |
| nitro groups | $-NO_2$ (aliphatic) | 1600-1530&1390-1300 |
| | $-NO_2$ (aromatic) | 1550-1490&1355-1315 |

## QUESTIONS

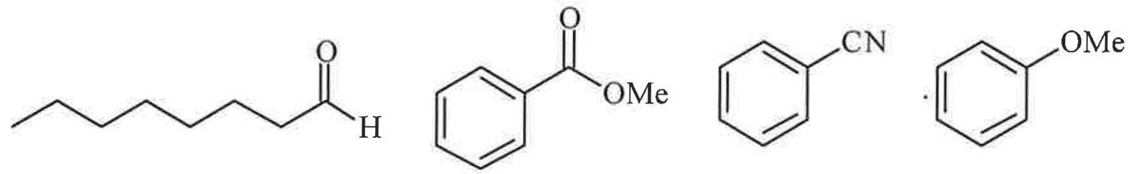
1. There are three different types of C-H bonds possible when you consider the hybridizations of the carbons involved. Which of the following would have the shorter and which the longer C-H bonds? Which would have the stronger and which would have the weaker C-H bonds? Which would absorb at the higher and which would absorb at the lower frequency in the C-H stretching region?

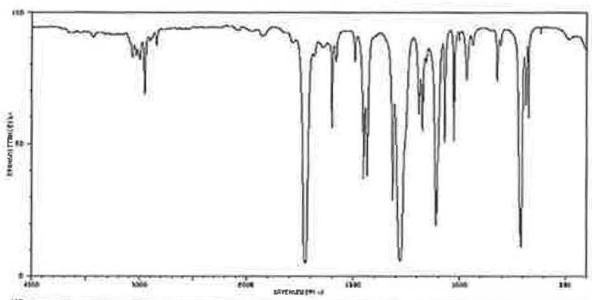


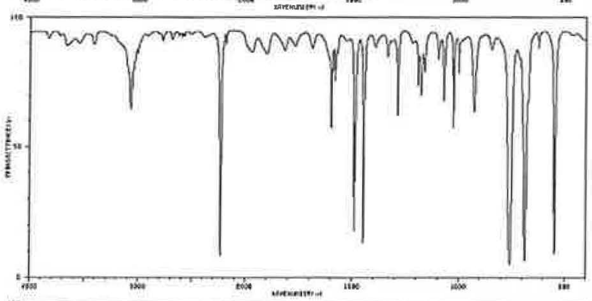
2. Would a C=O stretch or a C-H stretch absorb more strongly in the IR?

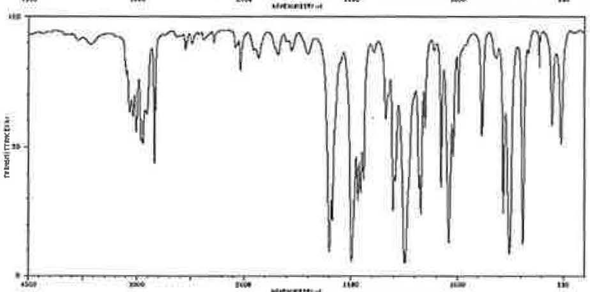
3. Both the C≡C and the C≡N absorb in the same region of the IR. Which would absorb more strongly?

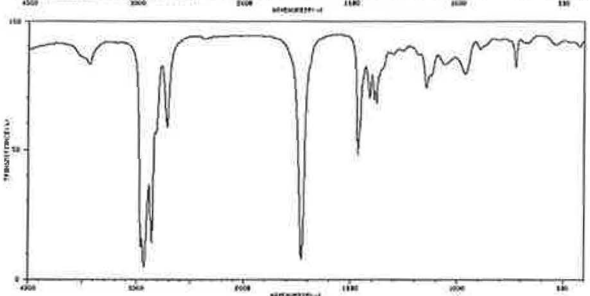
4. Below are four IR spectra. Assign one spectrum to each of the following compounds.











# GAS CHROMATOGRAPHY – MASS SPECTROSCOPY (GC-MS)

Reference: Fong, L. K. Separation and Identification of a Mixture of Group 6 Transition-Metal Carbonyl Compounds Using GC-MS in the General Chemistry Curriculum. *J. Chem. Educ.* **2004**, *81*, 103-105.

## INTRODUCTION

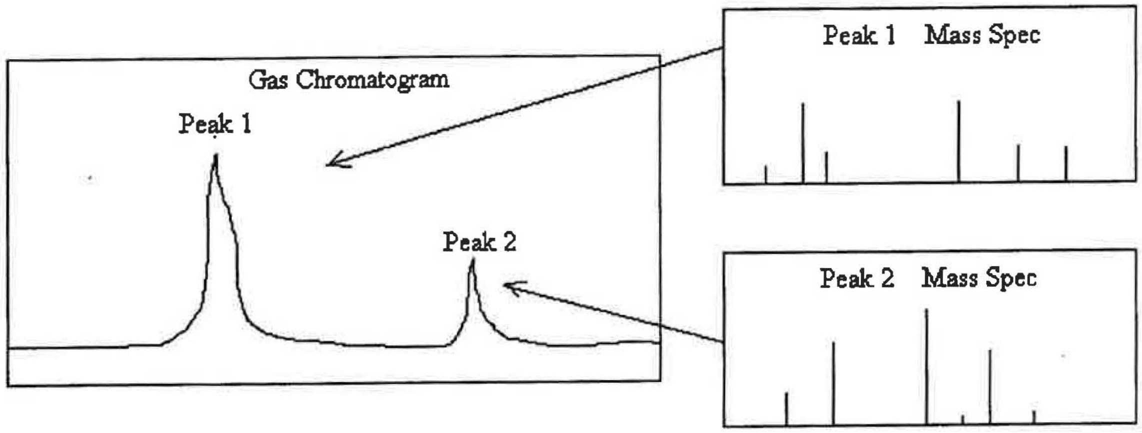
A characteristic feature of transition metals is their ability to form compounds in which carbon monoxide acts as a ligand. These types of complexes are commonly referred to as transition metal carbonyl complexes. Many of these compounds serve as important starting materials for the synthesis of other transition metal complexes as well as having importance in structure analysis and in industrial processes. Whereas the complexes in this experiment consists of only mononuclear species (e.g. $Ni(CO)_4$), polynuclear transition metal carbonyl compounds also exist (e.g. $Co_2(CO)_8$, $Fe_3(CO)_{12}$ and $Fe_2Os(CO)_{12}$).

In this experiment, you will determine the identity and the amount of each metal carbonyl complex in your unknown mixture by using the combined technique of gas chromatography - mass spectrometry (GC MS).

## GAS CHROMATOGRAPHY

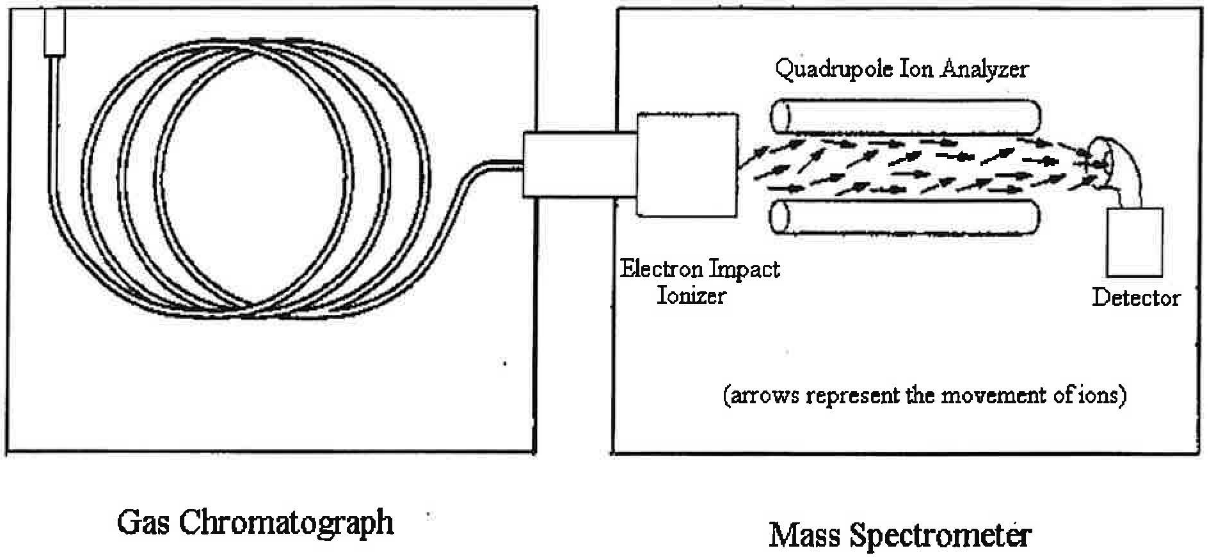
The term chromatography indicates a general method whereby a mixture of components are partitioned between a stationary phase and a mobile phase. For gas chromatography, the mobile phase is an inert gas such as helium and the stationary phase is a liquid film supported on a solid material inside a column. Typically, a solution of the mixture is injected into the heated inlet port whereby it is carried by the gas stream of helium into the column. As this mobile phase passes over the stationary phase, the components in the mixture are equilibrated between the two phases based upon their distribution coefficients (e.g. there affinity to the solid support versus the gaseous mobile phase). Components which have a greater affinity for the solid support will stay on the column longer and as such will have a larger retention time (tR). Under the right conditions, the components can be successfully separated on the column. In a typical GC analysis, the temperature of the column can be varied throughout the separation in order to maximize the separation between the components.

Once the components come off the column, they are passed into the detector. For today's experiment, the detector will be the mass spectrometer. As an example, a typical chromatogram is shown below. In this illustration, a mixture of two components was successfully separated on the GC column. The components, upon exiting the column, were immediately placed into the inlet port of the mass spectrometer. The result is that each component will give rise to its own unique mass spectrum. Interpretation of the results is discussed in the next section.



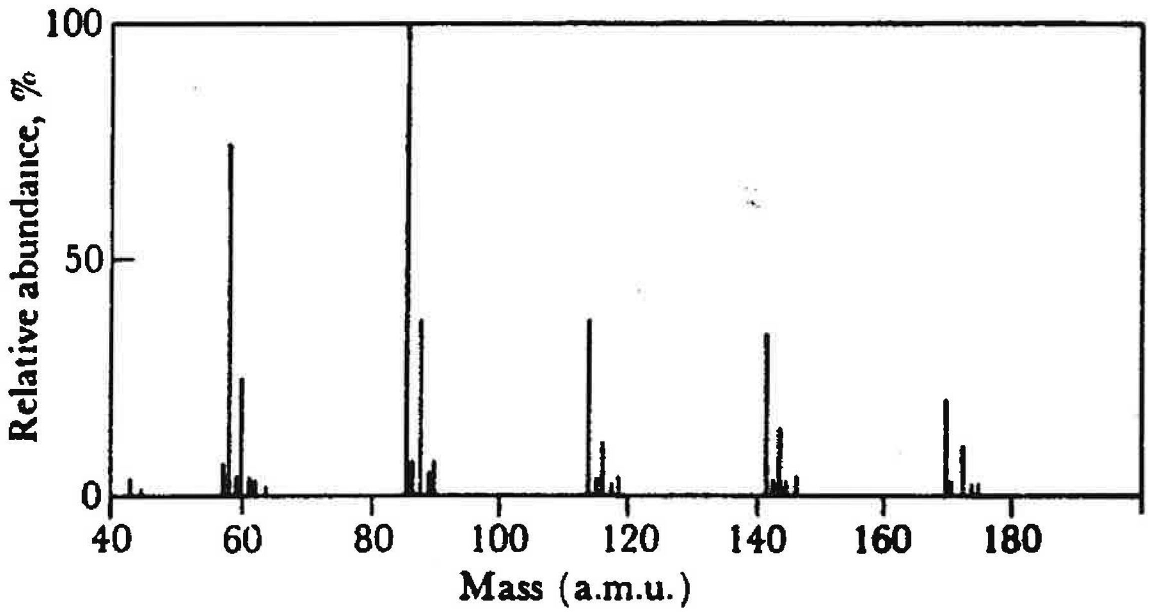

## MASS SPECTROMETRY

Mass spectrometry allows for the determination of the atomic mass of a given species. In this process, a sample is injected into the inlet port where upon it becomes vaporized. For a GC MS system, when the sample exits the gas chromatography column, it enters directly into the inlet port of the mass spectrometer. The gaseous sample is then subjected to an electron beam which ionizes the sample by removing electrons thereby creating positive charged species. The charged species can undergo fragmentation forming additional cationic species. The majority of ions produced will have a charge of +1. Any uncharged molecules or fragments are pumped away. The ion analyzer is a quadrupole mass analyzer which consists of four rods situated parallel to each other (see schematic diagram on the following page). This analyzer uses positive and negative voltages to control the path of the ions. This path depends upon the mass to charge ratio (m/z) of the ions. By varying the voltages, different masses can travel successfully down the path to reach the detector. This allows for the separation of the ions based on their respective masses. The cations will ultimately strike a detector plate which allows for the determination of their respective masses (based on $^{12}C$ being equal to 12.000000 amu).




### *Schematic Diagram for a Quadrupole Ion Analyzer*

The mass spectrometer is a very sensitive instrument which can easily separate out isotopes of various atoms. For example, given below is the mass spectrum of $Ni(CO)_4$. The y-axis is labeled as Relative Abundance and the x-axis indicates the ratio of mass to the number of charges on the ions (m/z). Typically, z = 1, so the x-axis is labeled as the relative mass. (note: z = 2 is also common).




**Mass Spectrum of $Ni(CO)_4$**

The fragmentation pattern shown can be interpreted as a sequential loss of the carbonyl ligands.

$$Ni(CO)_4^+ \xrightarrow{-CO} Ni(CO)_3^+ \xrightarrow{-CO} Ni(CO)_2^+ \xrightarrow{-CO} Ni(CO)^+ \xrightarrow{-CO} Ni^+$$

**PROCEDURE**

Determination of the Identities of $M(CO)_x$, $M'(CO)_x$, and $M''(CO)_x$

In order to determine the identities of the metal carbonyl compounds used in this experiment, one needs to analyze the mass spectrum of each compound and compare the experimentally determined atomic mass with the list of possible unknowns. For this experiment, mass spectra of each metal carbonyl have been collected and will be made available for analysis. This will be discussed in the **Analysis** section.

Determination of the Concentration of $M(CO)_x$, $M'(CO)_x$, and $M''(CO)_x$ in your Unknown

In order to determine the concentration of the unknown metal carbonyls in your mixture, you will need to prepare three solutions containing known concentrations of the metal carbonyls. In addition, you will prepare a diluted solution of your unknown mixture. These solutions will be prepared by dilution of the given stock solutions. The solvent of choice for this experiment is hexane. Not only are the metal carbonyls readily soluble in hexane, hexane is eluded off of the GC column prior to the metal carbonyls and as such, will not interfere with the analysis. However, because hexane is very volatile at room temperature (normal boiling point = 69 °C), you must work quickly and carefully to minimize evaporation of the solvent. Failure to do so will cause a substantial error in the calculated concentrations of the prepared solutions. (Note that the concentrations of the metal carbonyls are themselves very low.) When holding your test tube, do not grab the bottom of the test tube with your hand. The heat generated from your hand can potentially cause evaporation of the hexane thereby giving rise to an error in your calculated concentrations.

Using the supplied solutions, prepare the following four diluted solutions in clean and dried test tubes (water will interfere with your analysis).

| Solution | ML of $M(CO)_x$ | mL of $M'(CO)_x$ | mL of $M''(CO)_x$ | ML of Unknown | mL of hexane |
|---|---|---|---|---|---|
| I | 2.00 | 1.00 | 1.00 | ----- | 4.00 |
| II | 2.00 | 2.00 | 2.00 | ----- | 2.00 |
| III | 2.00 | 3.00 | 3.00 | ----- | ----- |
| IV | 2.00 | ----- | ----- | 6.00 | ----- |

Carefully mix the solutions with a clean glass rod. Be sure to avoid cross contamination. Assuming volumes are additive, you will be able to calculate the concentrations of the metal carbonyl species in the above mixtures (except for solution IV, where only the concentration of $M(CO)_x$ can be determined). In addition, solutions I, II and III will be used to prepare a calibration curve to determine the concentration of $M'(CO)_x$ and $M''(CO)_x$ in the unknown mixture. The concentration of $M(CO)_x$ will be known in all four solutions. This is necessary because we will be using $M(CO)_x$ as an internal standard to determine the concentrations of the other two carbonyl compounds.

Using the above solutions, you will need to prepare 4 GC vials with about 1 mL of each sample. Be sure to label each vial with your group's initials and the solution type (I, II, III or IV). Place a serum cap onto the vial to minimize evaporation and give these to your instructor. He/she will demonstrate the use of the GC-MS instrument with your samples.

## ANALYSIS

### Identification of the Metal Carbonyl Compounds

The chromatographic peaks of the pure (99%) metal carbonyl compounds along with their corresponding mass spectra are located in the computer. For each total ion chromatogram, you will see one major peak which represents the metal carbonyl compound. The retention time (tR) is the time it takes for the sample to be eluded off of the column. As long the conditions remain the same, this metal carbonyl compound will always (within experimental error) come off of the column with the same tR value. Therefore, once you identify the metal carbonyl compounds in each of the spectra, their respective tR values will allow you to identify the peaks in the solutions you prepared earlier (solutions I, II, III, and IV).

The possible identities of the metal carbonyl compounds are listed below. To determine the identity, you need to match the parent peak to the calculated atomic mass.

| | | | |
|---|---|---|---|
| $V(CO)_6$ | $Cr(CO)_6$ | $Mo(CO)_6$ | $W(CO)_6$ |
| $Fe(CO)_5$ | $Ru(CO)_5$ | $Os(CO)_5$ | $Ni(CO)_4$ |

### Calibration Curve

In order to determine the concentration of $M'(CO)_x$ and $M''(CO)_x$ in your unknown mixture, the presence of an internal standard, of which you will know its concentration, will be used. Referring back to your preparation of your initial solutions, all of these solutions should contain close to 2.00 mL of $M(CO)_x$. Since the total volume is identical (for the most part), the concentration of $M(CO)_x$ is known and is the same in all four solutions. In addition, the concentrations of the other two metal carbonyl compounds in solutions I, II and III are also known.

From the gas chromatograph, the area under each peak (area = total ions) is directly related to the amount of the compound present. For example, given two samples of the same $M(CO)_x$, the sample which contains more $M(CO)_x$ will have a greater peak area. When different compounds are compared, such as $M(CO)_x$ versus $M'(CO)_x$, a direct comparison cannot be made since each compound fragments differently in the mass spectrometer and different compounds can have potentially different ionization efficiencies. For example, suppose you have a $1.00 \times 10^{-6}$ M solution of X and a $1.00 \times 10^{-5}$ M solution of Y. A first analysis would suggest Y to have a larger peak area based on the given concentrations. However, the peak area of X might be larger than Y if X tends to generate more ions in the mass spectrometer. The best way to overcome this is by using an internal standard.

The use of the internal standard will allow for a more accurate determination of the concentrations of $M'(CO)_x$ and $M''(CO)_x$. Instead of using the total area under the gas chromatograph peak, we will select specific ions to represent each metal carbonyl. This method will allow for a better determination of the true concentration of the metal carbonyl compounds.

To prepare your calibration curve, you will need to calculate out the concentrations of the metal carbonyls in solutions I, II and III. In addition, you will need to determine specific ion abundances for the selected ions. Once you have your data, you will need to prepare a graph of

$[M'(CO)_x]/[M(CO)_x]$ versus selected ion abundance for $M'(CO)_x$ /selected ion abundance for $M(CO)_x$

and a graph of

$[M''(CO)_x]/[M(CO)_x]$ versus selected ion abundance for $M''(CO)_x$ /selected ion abundance for $M(CO)_x$

Both of these graphs should give you a nice straight line. These graphs can now be used to determine the concentrations of $M'(CO)_x$ and $M''(CO)_x$ in your unknown. When you analyze the gas chromatogram of your unknown mixture, you will know the concentration of your internal standard $M(CO)_x$, the abundance of the selected ions for your internal standard and of the other two metal carbonyls. The only missing value is the concentrations of the two metal carbonyl compounds. These can now be determined from the graph. A sample graph is attached at the end of this document.

Atomic Mass

The atomic mass for each metal can be determined by taking the weighted average of the isotopes. From the tabulated print-out, determine which cluster of peaks is the lone metal ion and given the table of isotopes on the next page, determine which peaks correspond to the metal (note that the mass number is approximately the atomic mass of the isotope). To determine the percentage of each isotope, divide the abundance of each isotope by the total abundance of all of the isotopes and multiply by 100. For example, suppose you have the following atomic masses and abundance:

| Mass | ion abundance | % abundance |
|---|---|---|
| 83.95 | 1345 | 14.56 |
| 84.85 | 5344 | 57.84 |
| 85.95 | 2550 | 27.60 |
| **Total** | 9239 | 100 |

The % abundance multiplied by the mass of the respective isotope gives the contribution of that isotope to the accepted atomic mass of the metal. Summing up these contributions gives the atomic mass of the metal.

$$(0.1456)(83.95\ \text{amu}) + (0.5784)(84.85\ \text{amu}) + (0.2760)(85.95\ \text{amu}) = 85.02\ \text{amu}$$

Table of Possible Isotopes

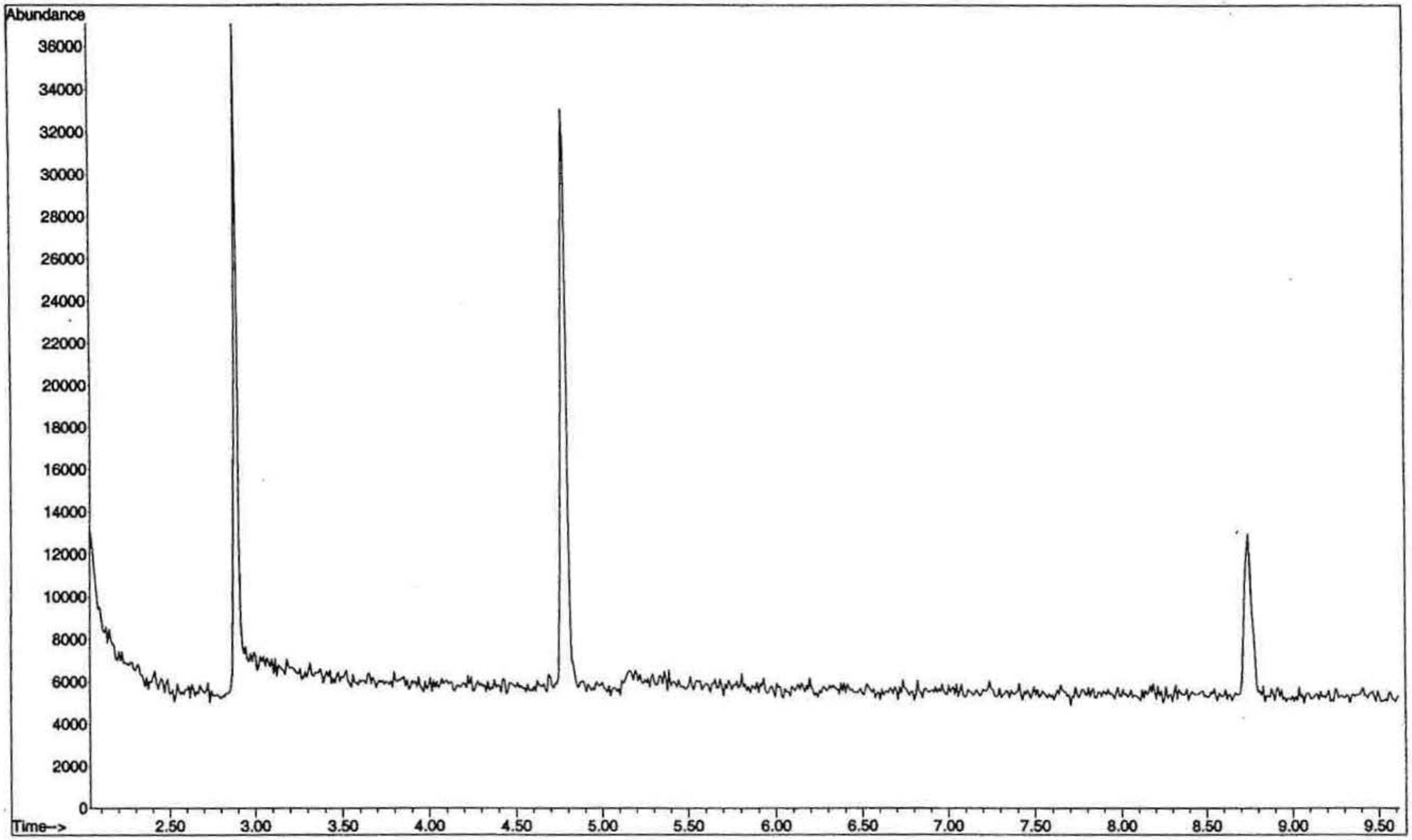
| Metal | V | Cr | Fe | Ni | Mo |
|---|---|---|---|---|---|
| Detectable Isotopes | $^{50}V$ | $^{50}Cr$ | $^{54}Fe$ | $^{58}Ni$ | $^{92}Mo$ |
| | $^{51}V$ | $^{52}Cr$ | $^{56}Fe$ | $^{60}Ni$ | $^{94}Mo$ |
| | | $^{53}Cr$ | $^{57}Fe$ | $^{61}Ni$ | $^{95}Mo$ |
| | | $^{54}Cr$ | $^{58}Fe$ | $^{62}Ni$ | $^{96}Mo$ |
| | | | | $^{64}Ni$ | $^{97}Mo$ |
| | | | | | $^{98}Mo$ |
| | | | | | $^{100}Mo$ |

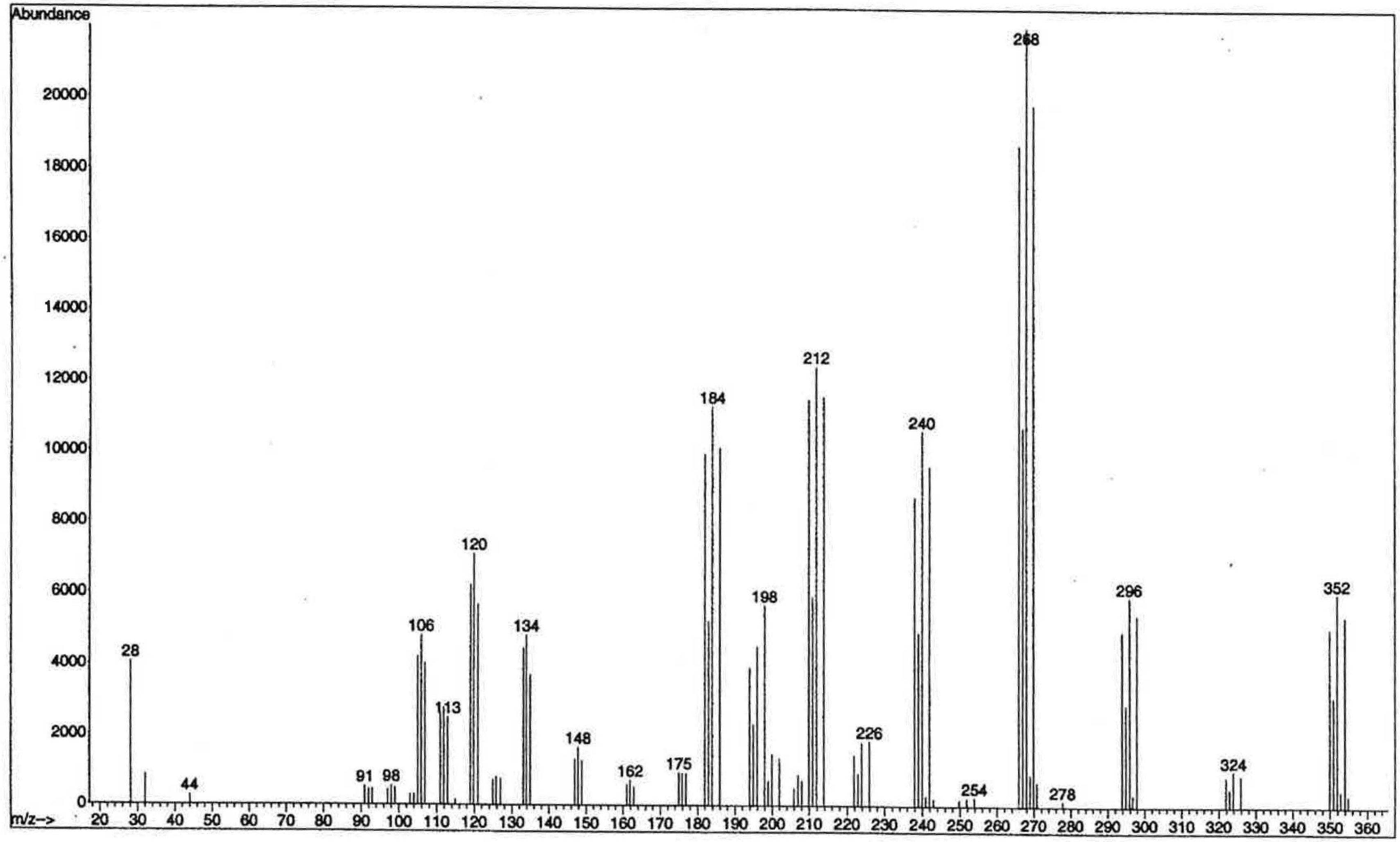
| Metal | Ru | Os | W |
|---|---|---|---|
| Detectable Isotopes | $^{96}Ru$ | $^{186}Os$ | $^{182}W$ |
| | $^{98}Ru$ | $^{187}Os$ | $^{183}W$ |
| | $^{99}Ru$ | $^{188}Os$ | $^{184}W$ |
| | $^{100}Ru$ | $^{189}Os$ | $^{186}W$ |
| | $^{101}Ru$ | $^{190}Os$ | |
| | $^{102}Ru$ | $^{192}Os$ | |
| | $^{104}Ru$ | | |

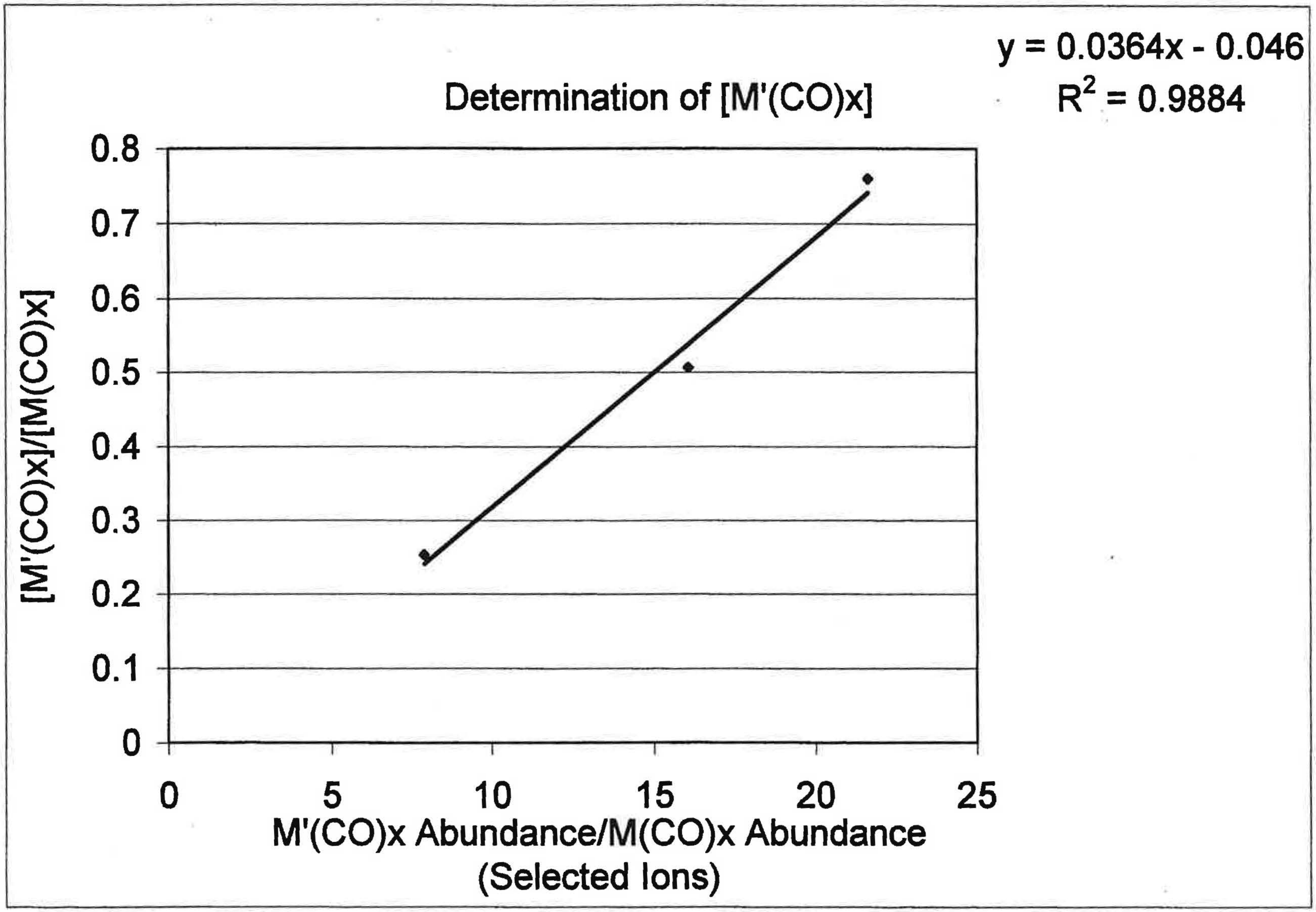
Analysis of Fragmentation Pattern

For each of your spectra, identify what is the parent peak, and how it fragments to form the other major peaks present. If you look carefully, you might notice clusters of peaks corresponding to doubly charged ions. These clusters are spaced closer together than for the singly charged ions, and the doubly charged peaks will be half the m/z value of the singly charged peaks.

The following are representative illustrations of actual samples. They are respectively, a total ion chromatogram (GC spectrum) of a mixture of the 3 metal carbonyls, the mass spectrum of $M''(CO)_x$, and a calibration curve for the determination of $[M'(CO)_x]$.


Abundance
36000
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Time-->
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
9.50


Abundance
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
m/z-->
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360
28
44
91
98
106
113
120
134
148
162
175
184
198
212
226
240
254
268
278
296
324
352


Determination of [M'(CO)x]
y = 0.0364x - 0.046
R2 = 0.9884
[M'(CO)x]/[M(CO)x]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
M'(CO)x Abundance/M(CO)x Abundance
(Selected Ions)

# ANALYSIS OF AIR BY MASS SPECTROMETRY

Reference: , J. D.; Hoops, G. C.; Samide, M. J. Mass Spectrometry for the Masses. *J. Chem. Educ.* **2004**, *81*, 1169-1171.

## Introduction:

Air is a *mixture* of many different *molecules and atoms*. The relative amounts of each component can differ depending on the environment. In this laboratory experiment, air samples from a variety of sources will be collected and then examined so that the relative amounts of each component in the air sample can be determined by mass spectrometry. Mass spectrometry is an advanced and modern technique that allows one to learn the molecular weights of and provide identity information for the different components in a sample.

## Before Work Begins:

Before work on this experiment begins, a table listing common molecules and elements in air should be constructed. Molecular and atomic weights should also be listed in the table.

## Materials:

Chemicals:
- baker's yeast
- 3% hydrogen peroxide ($H_2O_2$)
- glacial acetic acid
- piece of clean steel wool

Equipment:
- 5 heavy-duty Ziploc bags
- glass vial
- a small plant
- transfer pipette
- mass spectrometer

## Instructor Demonstration:

With a glass stir rod, a piece of steel wool is pushed into the bottom of a 100 mL graduated cylinder that contains 5 mL of glacial acetic acid. Next, 250 mL of water is added to a 500 mL beaker and the cylinder is inverted and placed into the beaker so that the mouth of the cylinder is about 1 inch from the bottom of the beaker. To prevent movement, the cylinder should be clamped into place. Students should check the water level in the cylinder periodically throughout the experiment.

**Sample Preparation:**

For each step below, a reaction will occur in which a gas will either be produced or consumed. An unbalanced chemical equation is provided for each step. These equations should be balanced and a one-sentence hypothesis describing the expected outcome of the air analysis should be written. *Remember - Safety goggles must be worn during all sample preparation and handling.*

1. Rust is caused by a chemical reaction between iron and oxygen. In the presence of an acid, this process is accelerated. Two pipette-fulls of glacial acetic acid should be added to a Ziploc bag. ***CAUTION:*** *Glacial acetic acid can cause severe burns. Any spills should be neutralized with a solution of sodium bicarbonate.* A golf ball sized piece of steel wool should then be placed into the bag and the bag should be sealed so that it contains some air. A minimum of 30 minutes should elapse before this sample is tested.

   Reaction: ___Fe (s) + ___ $O_2$ (g) → ___ $Fe_2O_3$ (s)

   Hypothesis:

2. Household hydrogen peroxide ($H_2O_2$) slowly decomposes into water and oxygen gas. Using a catalyst can accelerate this process. One common use of hydrogen peroxide is for cleaning out scrapes and scratches. The bubbles that form during this process are caused by the decomposition of the peroxide catalyzed by blood. Another catalyst is baker's yeast. Two scoopula-tip-fulls of yeast should be placed into a Ziploc bag. The glass vial should be filled with hydrogen peroxide solution and carefully placed into the bag. While keeping the vial upright, as much of the air inside the bag should be squeezed out. Finally, the vial should be tipped and the contents of the bag mixed.

   Reaction: ___ $H_2O_2$ (l) → ___ $H_2O$ (l) + ___ $O_2$ (g)

   Hypothesis:

3. During respiration, a body takes in and consumes oxygen and creates and releases carbon dioxide. Sealing a bag around the mouth, 3 to 4 breaths should be taken of the air in the bag, inhaling and exhaling the air in the bag. After the final exhale, the bag should be sealed.

   Hypothesis:

4. Through the process of photosynthesis, plants consume carbon dioxide from the air and release oxygen. A living plant was sealed in a plastic bag so that a large amount of air was sealed in the bag with the plant. This was done so that the plant would have a minimum of one day to affect the air sample composition in the plastic bag before this analysis.

   Reaction: ___ $CO_2$ (g) + ___ $H_2O$ (l) → ___ $C_6H_{12}O_6$ (s) + ___ $O_2$ (g)

   Hypothesis:

5. Combustion engines consume oxygen in order to efficiently burn fuel. The exhaust from a running car should be collected in a plastic bag.

   Reaction: ___ $C_8H_{18}$ (l) + ___ $O_2$ (g) → ___ $CO_2$ (g) + ___ $H_2O$ (g)

   Hypothesis:

6. With the five air samples, the analysis can now begin.

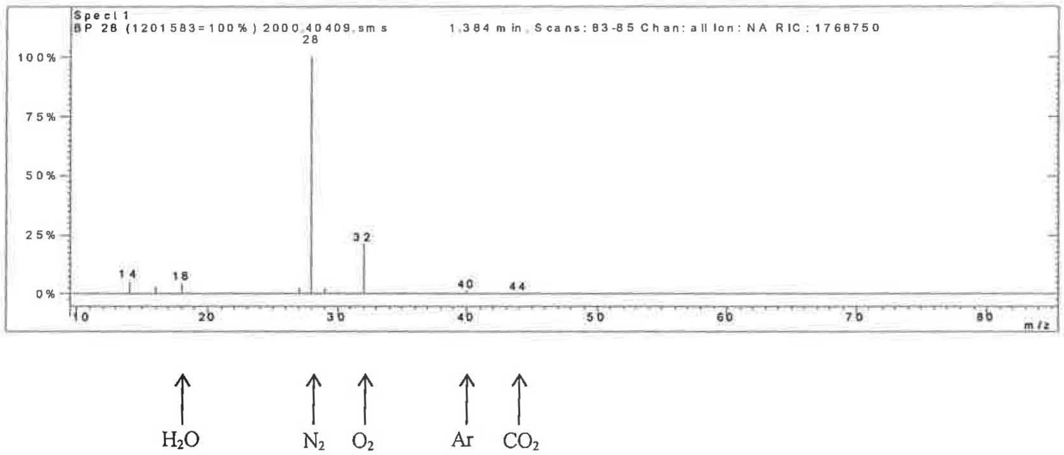
**Sample Analysis:**

Each analysis will require 2 minutes and the instructor will provide assistance for the first analysis. After the initial training, students will be able to perform the analysis and use the equipment. For all samples, you must use a gas-tight syringe and each injection will require 5 microliters (5 μL) of gas sample. Sample analysis should be accomplished in the following order.

A. Background (done by the instructor)
B. Bag 2: Yeast
C. Bag 3: Breath
D. Bag 4: Plant
E. Bag 5: Exhaust
F. Bag 1: Steel wool

**Data Analysis and Questions:**

A mass spectrum gives two different types of information. First, the spectrum shows a series of peaks, each at a different mass. This can be used to identify what components are in the sample.




Second, the mass spectrum shows intensity information. This information is useful because it describes the relative amount of each component present. Example intensity data is shown below.

| Ion | Int | %BP | Ion | Int | %BP | Ion | Int | %BP | Ion | Int | %BP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 68167 | 6 | 22 | 2333 | 0 | 27 | 36500 | 3 | 33 | 833 | 0 |
| 17 | 4083 | 0 | 23 | 1417 | 0 | 28 | 1201583 | 100 | 34 | 1917 | 0 |
| 18 | 56083 | 5 | 24 | 3667 | 0 | 29 | 33167 | 3 | 38 | 500 | 0 |
| 20 | 2750 | 0 | 25 | 3583 | 0 | 30 | 12917 | 1 | 39 | 833 | 0 |
| 21 | 2917 | 0 | 26 | 7583 | 1 | 31 | 5333 | 0 | 40 | 18500 | 2 |
| | | | | | | 32 | 255250 | 21 | 44 | 3750 | 0 |

The **Ion** column identifies the m/z of the compound and the **Int** column shows the number of ions that the instrument detected. The **%BP** column is for advanced analyses and will not be used for this experiment. In general, the bigger the **Int**, the more material you have.

But, in order to compare the results from one mass spectrum to another, the data needs to be normalized. In other words, only the ratio of two peaks can be compared. For example, the nitrogen intensity value from one mass spectrum cannot be compared directly to the nitrogen intensity value from another mass spectrum. Reasons for this include the difficulty in injecting the same amount of sample each time.

But by examination of the ratio of two peaks, these types of comparisons can be made. In general, each ratio is created so that the intensity for the gas that is expected to change is divided by the intensity for a gas not expected to change.

As an example, using the data tabulated above, a comparison of the oxygen level can be made with those of a background sample. To make this comparison, the oxygen intensity needs to be compared to the nitrogen intensity, because the amount of nitrogen is not expected to change during the course of these experiments. Therefore, the intensity ratio for the sample being tested (using the data tabulated above) is:

$$\frac{\text{intensity of changing variable}}{\text{intensity of unchanging variable}} = \frac{\text{intensity of oxygen peak}}{\text{intensity of nitrogen peak}} = \frac{255250}{1201583} = 0.21$$

The intensity ratio for the background (using made-up numbers) might be:

$$\frac{\text{intensity of changing variable}}{\text{intensity of unchanging variable}} = \frac{\text{intensity of oxygen peak}}{\text{intensity of nitrogen peak}} = \frac{230241}{1211793} = 0.19$$

On the basis of these ratio values (0.21 > 0.19), it is clear that the sample of air that was tested has more oxygen present than a background sample.

In fact, a percent change can be calculated according to the formula:

$$\text{Percent change} = \frac{(\text{sample ratio} - \text{background ratio})}{(\text{background ratio})} \times 100$$

For the example above, the percent change is calculated to be 10.5%. This indicated that there is roughly 10% more oxygen in the tested sample than in the air sample.

For the analysis of the data collected in this experiment, this example should be followed and a comparison should be made for the intensity ratios for different gases in the sample, keeping in mind the hypotheses made about each sample.

1. Calculate and compare the oxygen to nitrogen intensity ratio of the background and of the yeast samples. What can be concluded about the yeast sample? Does the yeast sample have more or less oxygen than the background? Does this result match with the hypothesis?

2. Calculate the carbon dioxide to nitrogen intensity ratio in both the background and the breathed air samples. Does the breathed air have more carbon dioxide than background air? Perform the same types of calculations to determine how the amounts of water and oxygen have changed. Do the data validate the hypotheses?

3. Calculate the carbon dioxide to nitrogen ratio for the plant sample and compare that to the same ratio for the background. Calculate the oxygen to nitrogen ratio for both the plant sample and for background? Do these result correlate with the hypotheses?

4. Calculate and compare the water to nitrogen ratio for the exhaust and the background. Perform the same analysis for the carbon dioxide to nitrogen ratio and the oxygen to nitrogen ratio. On the basis of the hypothesis, do these results make sense?

5. Calculate and compare the oxygen to nitrogen ratio for the steel wool sample and to the background. Was the chemical equation for the reaction of iron correct? Does this match with the hypothesis?

6. *Optional.* On the basis of the results from question 5, explain what happened with the inverted cylinder. Why did the water level inside the cylinder rise?

**Conclusions:**

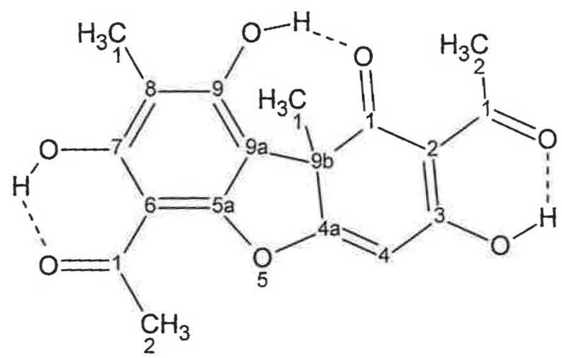
Think about the data and what it revealed about the chemical reaction studied. Is there a particular sample that proved to be the most interesting? Why? What was learned about the environment in which the air samples were collected? Are there any questions that this data didn't answer? Are there any questions that came to mind while doing this experiment?

# USNIC ACID AND THE INTRAMOLECULAR HYDROGEN BOND

Reference: Green, T. K.; Lane, C. A. Usnic Acid and the Intramolecular Hydrogen Bond. *J. Chem. Educ.* **2006**, *83*, 1046-1048.

## Introduction

Usnic acid is a common and abundant lichen metabolite that possesses three intramolecular hydrogen bonds, along other interesting properties, such as being an antibiotic, and has been the subject of hundreds of papers.



Usnic Acid

Usnic acid appears to be naturally produced exclusively by lichens. Barton first synthesized it in the laboratory in 1956. Usnic acid can be found in many lichens; it is particularly abundant in specimens of the genus Usnea, known collectively as the "beard lichens", which grow on trees and are widespread throughout North America. Usnea is the only genus with a distinctive rubberband-like elastic central cord evident when the lichen is slowly pulled apart lengthwise. We will extract and purify (-) usnic acid from *Cladina Stellaris* (star-tipped reindeer lichen, a ground lichen) or (+) usnic acid from *Usnea sp.* Use the following procedure.

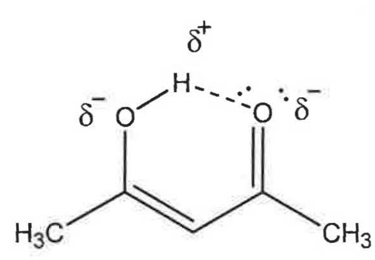
## Experimental

Obtain a $^{1}H$ NMR spectrum using *d*-chloroform. You will have to increase the spectral window in order to observe the most downfield signal at near 19 ppm. Also obtain an IR spectrum of the same solution following your NMR analysis.

## Computational Experiment; Hydrogen bonding and NMR spectroscopy

**a. Background on Hydrogen Bond.** Usnic acid possesses three intramolecular hydrogen bonds as discussed in class and shown above. You will note the three downfield absorptions in the $^{1}H$ NMR spectrum that correspond to the bridging hydrogens of these hydrogen bonds. A goal of this computational experiment is to estimate the relative strengths of these hydrogen bonds and correlate them to the chemical shifts in the $^{1}H$ NMR spectrum. You will employ the semi-empirical AM1 method.

Hydrogen bonding results in shifts of electrons from the proton acceptor (carbonyl) to the proton donor (hydroxyl) as shown below for the enol form 2,4-pentadione, a molecule that you may be familiar with.

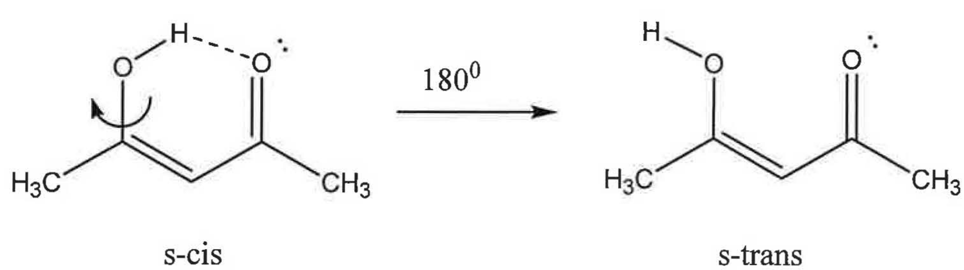



Enol form of 2,4-pentadione

Interestingly, this electronic redistribution bypasses the bridging hydrogen and becomes distributed throughout the proton donor molecule or group. Thus, one can expect a general deshielding of the bridging hydrogen in the $^1$H NMR spectrum with increasing strength of the hydrogen bond. The question then becomes one of strength; the strongest hydrogen bond should yield the largest chemical shift for the hydroxyl hydrogen. You will estimate the strength of each hydrogen bond of usnic acid and then correlate the strengths to the respective chemical shifts of the bridging hydrogen. Additionally, you will measure the positive charge on the bridging hydrogen to see whether it also correlates with chemical shift.

**b. Build, Minimize, and Record OH Hydrogen Charges.** Construct and model build usnic acid using HyperChem. After you model build, be sure that all hydroxyl groups and carbonyl groups are pointing toward each other in order to form a hydrogen bond. If they are not, you will need to use the Set Bond Torsion tool under Edit to rotate the groups by $180^0$ so that they are hydrogen bonded. Minimize the structure using the AM1 method using a convergence limit of 0.1. Once minimized, save the structure as a .hin file. Now display and record the charges on the hydroxyl hydrogen in Table 1.

**c. Estimate H-Bond strengths.** The most common approach is to calculate the hydrogen bond energy as the energy difference between the minimized hydrogen bonded structure and one in which the hydroxyl bond has been rotated by $180^0$ (s-cis and s-trans conformations) as shown below.



The difference in the heats of formation of these two conformations represents the heat of hydrogen bond formation, $-\Delta H_{H\text{-bond}}$.

$$-\Delta H_{H\text{-bond}} = H_{f,s\text{-trans}} - H_{f,s\text{-cis}}$$

This approach assumes that the difference in energies of the s-cis and s-trans is due primarily to the hydrogen bond that forms. For 2,4-pentadione, this assumption is reasonable, but the situation for usnic acid is somewhat more complicated because of the 8-CH3 (see above). When the either the 7-OH or 9-OH is rotated away form the carbonyl, it creates a significant steric effect with the 8-$CH_3$, which is not present in the hydrogen bonded structure. We will do our calculation on usnic acid without the 8-$CH_3$ group present, with the assumption that its removal has minimal effect on the strength of the hydrogen bond. We will call this the "corrected" hydrogen bond strength, $-\Delta H'_{H\text{-bond}}$.

**d. Detailed Procedure for Hydrogen Bond Strengths.** Delete the 8-CH3 group from your original usnic acid and replace it with a hydrogen atom. Now re-minimize and record the heat of formation in Table 2. This molecule is the all s-cis structure. Save your structure.

Table 1.

| OH Group | $H_{f,s\text{-cis}}$ cal/mol | $H_{f,s\text{-trans}}$ kcal/mol | $-\Delta H'_{H\text{-bond}}$ kcal/mol | $\delta_{OH}$, ppm[b] | $H^{\delta+}_{OH}$ |
|---|---|---|---|---|---|
| Usnic 3-OH | | | | | |
| Usnic 7-OH | | | | | |
| Usnic 9-OH | | | | | |

Now, build the 7-OH s-trans by selecting the s-cis dihedral $C_6$-$C_7$-O-H and setting it to $180^0$ using Set Bond Torsion. Minimize, save, and record the heat of formation.

Now, build the 3-OH s-trans by selecting the s-cis dihedral $C_2$-$C_3$-O-H and setting it to $180^0$ using Set Bond Torsion. Minimize, save, and record the heat of formation.

Finally, build the 9-OH s-trans by selecting the s-cis dihedral $C_9$-$C_{9a}$-O-H. You will notice that when you select this dihedral, it is about –11 degrees (where the other s-cis dihedrals were near 0). You will want to rotate this dihedral by 180 degrees. Therefore Set Bond Torsion = 180 + -11 = 169 degrees. Before you minimize, you need to restrain this bond to maintain the dihedral. Go to Name Selection (under Select), choose Other and type dihedral. Deselect and go to Setup, choose Restraints, Add 4-dihedral, and set the restrained value to Other 169. The force constant should be set to Other 10000. Now minimize, save and record the heat of formation.

**e. Results and Questions**

1. Calculate $-\Delta H'_{H\text{-bond}}$ (should be positive value) and record in Table 1. Record the measured chemical shifts in Table 1 based on your estimated hydrogen bond strengths. Make a plot of $\delta_{OH}$ versus $-\Delta H'_{H\text{-bond}}$ and determine the slope and intercept of the curve.
2. Do the same for $\delta_{OH}$ versus $H^{\delta+}_{OH}$. Are the positive charges on the atoms consistent with what your expect regarding the observed chemical shifts and the nature of the hydrogen bond? Explain.

## Optional Computational Experiment; Hydrogen Bonding and IR spectroscopy

**Assignments of Carbonyl Stretching Vibrations**. There are three carbonyl absorptions in your IR spectrum. Identify them and report them to your instructor or TA for verification. Retrieve your original minimized usnic acid .hin file. Measure the C=O bond lengths and record in Table 2. Calculate the vibration spectrum using Compute and then Vibrations. View the vibrational spectrum and locate the carbonyl absorptions by animating them. Record their frequencies in Table 2. Based on your assignments of the computed frequencies, make assignments of the experimental frequencies.

Table 2.

| C=O bond | AM1 C=O str, $cm^{-1}$ | Exp C=O str, $cm^{-1}$ | AM1 C=O Bond Distance, Δ |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

# FRIEDAL-CRAFTS ACYLATION OF AN UNKOWN COMPOUND

Reference: Reeve, A. M. A Discovery-Based Friedel-Crafts Acylation Experiment: Student-Designed Experimental Procedure. *J. Chem. Educ.* **2004**, *81*, 1497-1499.

## INTRODUCTION

Aromatic systems undergo substitution reactions by an electrophilic pathway. That is, the nucleophilic pi electrons of the aromatic ring attack strong electrophiles. An intermediate carbocation is formed that rapidly loses $H^+$ to reform the aromatic system. The overall result is the substitution of an aromatic hydrogen with the electrophile. In the case of Friedel-Crafts acylation, the electrophile is an acylium ion, formed by the reaction of an acid chloride with aluminum chloride. A general mechanism is shown below.

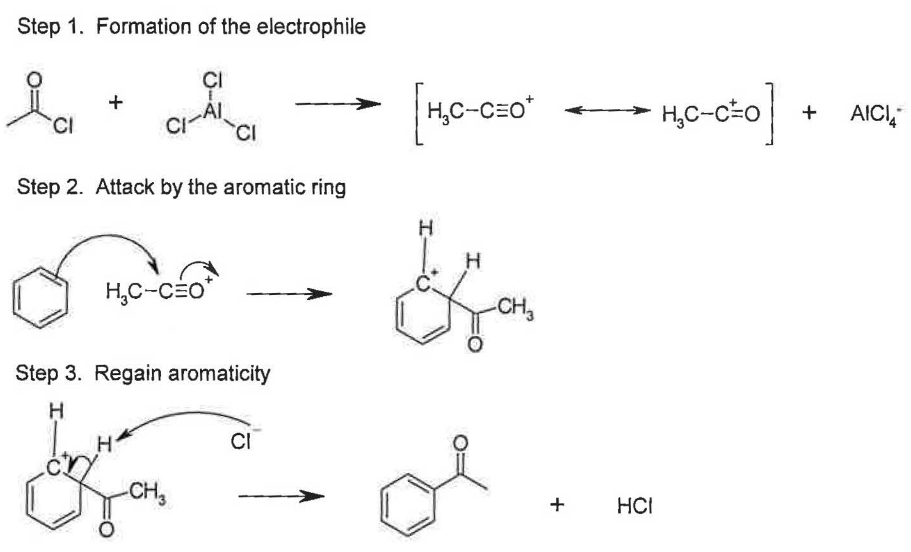



*FIGURE.* Friedel-Crafts acylation of benzene.

In this experiment, you will be given a sample of an unknown aromatic compound. You will conduct the reaction and determine the identity of the product (and therefore the starting material) by IR and NMR spectroscopy. The possible starting materials are toluene, ethylbenzene, and methoxybenzene (anisole).

## Safety and Hazards

Please wear gloves for this experiment. Aluminum hloride is water sensitive, an irritant, and corrosive. It will react with the moisture on your skin to liberate HCl. Handle it with care, weigh out only what is necessary, and work quickly. Acetyl chloride is also corrosive. Be sure to keep it in the hood. Keep all reagent bottles tightly capped. Discard aqueous waste down the drain with lots of water. Collect organic waste into the appropriate waste containers. Handle syringes with care. Cap and dispose of used needles in the biohazard container.

## Procedure and Notes

The procedure is written in the simple past tense as you would see in a journal article.

### Mini-Scale

Anhydrous aluminum chloride (5.5 mmol, 1.1 equiv.) and 1.5 mL of methylene chloride were placed into a 10 mL round bottomed flask equipped with a stir bar. A Claisen head, septum, cap, and reflux condenser were attached and the stirred mixture was cooled in an ice/water bath. Acetyl chloride (5.5 mmol, 1.1 equiv) and 1.0 mL of methylene chloride were combined in a conical vial. The clear, colorless solution was added to the reaction flask dropwise using a syringe over 5 - 10 minutes with stirring. The aromatic compound (5.0 mmol, 1.0 equiv) was dissolved in 1.0 mL of methylene chloride. This solution was added to the cooled reaction mixture dropwise over 5 minutes using the same syringe. After addition was complete, the cooling bath was removed and the reaction mixture was allowed to come to room temperature. After 15 minutes at room temperature, the reaction mixture was poured carefully, with swirling, into 5 g of ice combined with 1.5 mL of concentrated HCl. The mixture was transferred to a separatory funnel and the organic layer was collected. The aqueous layer was extracted with 5-10 mL of methylene chloride. The combined organic layers were extracted with two portions of saturated sodium bicarbonate and dried over anhydrous $MgSO_4$. The drying agent was removed by gravity filtration into an appropriately sized round bottomed flask. The methylene chloride was removed by rotary evaporation. The product was weighed and analyzed by infrared and NMR spectroscopy and TLC (ethyl acetate:hexane :: 1:4) in comparison with the proposed starting material.

**Notes**

1. Do not wash your glassware just before doing this experiment. Your glassware must be clean and dry. Do not wash your syringe (addition funnel) between adding the acetyl chloride and the aromatic compound.

2. Weigh out the aluminum chloride quickly and keep the container tightly capped.

3. Obtain the IR spectrum as a thin film for liquids or as a solution in $CHCl_3$ for oils. Put the analysis in your notebook. Obtain an NMR spectrum in the normal way in $CDCl_3$. Also put the analysis of the NMR spectrum in your notebook. Obtain an accurate integration of your NMR spectrum. If you suspect that your product is contaminated with starting material, carefully integrate the starting material peaks separately so you can calculate an approximate percent of each.

4. Once you have proposed an identity for your product, calculate a percent yield.

5. Obtain literature NMR and IR spectra for your product and for the ortho isomer. Do you see any evidence in either your experimental NMR or IR spectrum that your product contains the ortho product?

**Molecular Modeling**

Use Spartan to construct a molecular model of the product you made. Click on the minimize icon on the toolbar to perform a quick minimization. Make a note of the energy value on the bar at the bottom right of the screen. This is a molecular mechanics strain energy in kcal/mol. Set up calculations at the semi-empirical AM1 level by clicking on Calculations in the Setup menu. Be sure Equilibrium Geometry and Ground state are selected (these are the defaults.) Submit your calculation. Once the calculation is complete, select Output from the Display menu. Print out the results, noting the energy of the compound. This is a heat of formation, in kcal/mol. Now construct a model of the ortho isomer. Perform the same calculations on it and print the results. Record both minimized energies with units. Does this explain the ortho-para isomer distribution in the Friedel-Crafts acylation reaction? Why or why not? Are the results from the molecular mechanics strain energy and the AM-1 heat of formation consistent? Print out your models in tube or ball and stick form from the View screen.

# APPENDIX D

Project Summary for Grant Proposal

"Mt. SAC Scholars Program"

(Awarded by the National Science Foundation)

## Project Summary

Mt. San Antonio College, a Hispanic-Serving institution and the largest single campus of California's 109 community colleges, seeks S-STEM funding to establish a scholarship program to recruit and support academically talented, financially needy students and enable them to attain higher education degrees in STEM disciplines. The project's goal and objectives will be achieved by providing a cluster of academic, enrichment and research support activities, designed to promote student success in the completion of an associate's degree and/or transfer to a baccalaureate institution as a STEM major. In addition, the program will provide a high level of student-faculty interaction and ample opportunities for the scholars to work with peers and bond as a student cohort. A minimum of 37 *academic scholarships* for a maximum of $2,700 per scholarship and 10 *research scholarships* for a maximum of $3,000 per scholarship will be awarded annually. Recipients will be recruited and selected from students planning to major in physical sciences (chemistry and physics), biological sciences, mathematics and engineering.

***Intellectual Merit.*** Through a wide range of support structures and resources, as well as the leadership of an experienced management team, the proposed initiative will ensure that scholarship recipients will receive all crucial support necessary to achieve success in STEM disciplines. The summer research experiences integrated in the program will provide invaluable opportunities for selected cohorts from the scholarship recipients to engage in authentic research in established STEM laboratories of the partner institutions. This experience will effectively prepare students for a seamless transfer to a baccalaureate program in their chosen STEM discipline, as well as increase their likelihood to pursue a career in the field upon graduation.

***Broader Impact.*** The project impact goes beyond just providing scholarships to eligible students in STEM disciplines. The proposed initiative will integrate many of the college's existing academic resources with the proposed S-STEM support programs into a unique infrastructure that promotes student success in rigorous STEM curricula and better prepares community college students to pursue a degree or a career in STEM fields. The project evaluation will assess the impact of the program on student retention and success, as well as contribute to the knowledge on effective practices that best prepare community college students for careers in STEM fields. The program will recruit the most deserving students, especially applicants from a diverse population that are historically underrepresented in the STEM disciplines.