Computational Chemistry

Chemistry 8021/5021, Spring Semester 2005

Instructor: Jiali Gao, 101G Smith Hall, 625-0769, gao@chem.umn.edu
TA: Vanessa Lynch, 224 Smith Hall, 626-0259, audette@chem.umn.edu
Time: Lectures: MWF 9:05 – 9:55 am, 331 Smith Hall
Labs: Selected F: 9:05-9:55 am, MSI at Walter Library
Office Hour: By appointment – you are welcome to see me or Vanessa at any time.

Text: Christopher J. Cramer, *Essentials of Computational Chemistry: Theories and Models*, 2nd Ed. Wiley & Sons, New York.

Two other recommended reference textbooks are on reserve with Maegan:
(1) Daan Frenkel & Berend Smit, *Understanding Molecular Simulaiton*, AP, NY, 2002; and
(2) Andrew R. Leach, Molecular Modelling: Principles and Applications, 2nd Ed., Prentice Hall, 2001.

In addition, I will make extensive use of handouts, covering major topics to be discussed in class. There is also a course web site at http://vesta.chem.umn.edu/classes/ch8021, containing most hand-outs, problem sets, exams, answers, and related materials.

The Course: There will be four project assignments during this semester. The lab projects will be accomplished using either the IBM SP Clusters and the SGI Graphics Workstations of the Minnesota Supercomputer Institute. The IBM SP Clusters may be accessed through the Internet from a unix workstation or a PC/Mac computer with ssh, whereas the SGI Graphics workstations, which are on the fifth floor in Walter, provide you with access to graphics programs such as InsightII/Discover/CHARMm and GaussView. We will also use VMD/NAMD which are freely available and can be easily installed on your PC. There will be one in-class midterm exam and one final oral presentation of a selected journal article(s) on a topic of your interest, though the selected paper must be approved by the Instructor.

My intension through this class is to provide students with the basic background for critical analysis of computational methodologies and their applications. I do not stress memorization of specific details of various topics that are covered in the course, rather, the emphasis is on the understanding and critical thinking. Therefore, the course is designed to use Monday and Wednesday classes to discuss basic concepts and, from time to time, mathematical derivations. On Fridays, class will focus on discussion of recent applications from selected journal articles, or will consist of laboratory demonstrations. For journal article discussions, prior reading of these articles, which I will provide them to you one week prior the discussion, are required.

Grading: The one group project and three individual project assignments will contribute 10% each to your overall grade. The mid-term exam adds an additional 25%, while the final oral presentation/critical analysis makes up 25%. I will award the final 10% based on classroom participation and discussion. You are welcome to discuss your performance with me at any time during the semester. Although a roughly distribution of half A's and half B's may be anticipated, I reserve the right to give more B's or all A's when it deemed appropriate. If you receive a total score of greater than 80 points, you will almost certainly receive an A. However, lower grades (C-F) may be assigned if you really work hard on that, and you will hear from me if that appears possible.

Policy on Academic Dishonesty: Scholastic dishonesty is any conduct described as follows (from CLA Classroom Grading and Examination Procedures).

"Scholastic dishonesty is any act that violates the rights of another student with respect to academic work or that involves misrepresentation of a student's own work. Scholastic dishonesty includes (but is not limited to) submitting the same or substantially similar papers for more than one course without consent of all instructors concerned; depriving another of necessary course materials; sabotaging another's work." If a student is guilty of scholastic dishonesty, the instructor will award a grade of zero on the work involved and will report the matter to the student's college Scholastic Conduct Committee.

Outline, Chemistry 5021/8021
Computational Chemistry
Spring, 2005
(Schedule is tentative)

I. Introduction

II. Molecular Mechanics and Force Fields.

   A. Force fields, potential energy functions, inter and intramolecular interactions, empirical parameters. (CJC, Chapter 2; ref. ARL, Chapter 4)
   B. Lab. InsightII and VMD.
   C. Molecular mechanics calculations, energy minimization, conformational analysis, vibrational frequencies, and normal mode analysis.
   D. Lab. CHARMM and InsightII.
   E. First Project Assignment.

III. Molecular Simulations.

   A. Monte Carlo Simulations
       a. Importance sampling and Metropolis sampling
       b. Basic algorithms and technical details
       c. Moves
   B. Molecular Dynamics Simulations
       a. Equations of motion and force calculations
       b. Diffusion
       c. Integration schemes
   C. Liquid Water
       a. Models
       b. Properties
   D. Ensembles
       a. Canonical and microcanonical Monte Carlo
       b. Isothermal-isobaric Ensemble Monte Carlo
       c. Grand-Canonical Ensemble Monte Carlo
       d. Constant T and P molecular dynamics

III. Liquids.

   A. Solvents (Polar and nonpolar)
   B. Solutions
   C. Acidity and Basicity, and Computation of pKa
   D. Continuum Solvation Models

IV. Structure and Dynamics of Proteins.

   A. Protein Structure and PDB

B. Building Models for Protein Structure and Energy Calcultions
C. Normal Mode Analysis
D. Molecular Dynamics of Proteins
E. Solvation

V. Free Energy Simulations.

A. Free Energy Perturbation
     a. Free energy of solvation
     b. Partition coefficients
B. Thermodynamic Integration and Umbrella Sampling
C. Potential of Mean Force for Condensed Phase Reactions
D. Hydrophobic Effects and Ion-Pair Interactions in Water

VI. Quantum Mechanics.

A. Gaussian and GaussView
B. Hartree-Fock Theory and Basis Sets
C. Semiempirical Methods
D. Electron Correlations
E. Density Functional Theory

VII. Combined QM/MM Methods.

A. Why and How to Combine QM and MM
B. Solvation and Solvent Effects
     a. Polarization
     b. Reaction profiles in soluton
C. Protein-Ligand Interactions
D. Modeling Enzymatic Reactions

Final Exam: presentation of a critical analysis of selected papers. (to be determined.)