Abstract: We have developed a family of organocatalysts for the controlled polymerization of lactones to well-defined polyesters of novel architectures and macromolecular topologies. These organocatalysts are both selective and highly active, exhibiting characteristics of living polymerization with turnover frequencies as high as 18 per second with turnover numbers up to 1000. In the presence of alcohols, N-heterocyclic carbenes are potent catalysts for the ring-opening polymerization of lactide to generate linear polylactides. In the absence of alcohols, N-heterocyclic carbenes mediate the zwitterionic polymerization of lactide or caprolactone to generate high molecular weight cyclic polyesters of narrow molecular weight distribution. The zwitterionic polymerization of lactones provides a new strategy for generating high molecular weight cyclic polyesters of defined molecular weight and molecular weight distribution. These cyclic polyesters exhibit different properties than their linear homologs by virtue of the topological constraint of connected chain-ends. Polymerization of caprolactone generates crystalline cyclic polyesters, enabling investigations on the role of the cyclic topology on the crystalline structure and morphology. The combination of organocatalytic ring-opening polymerization with living free radical methods generates a variety of novel architectures, including linear and branched amphiphilic block copolymers. Metal-free block polymers generated with organic catalysts assemble into nanostructures that encapsulate drugs and biological probes. The unusual stereocomplexation phenomena characteristic of enantiomeric polylactides directs their assembly of block copolymers; we have generated a new family of thermoresponsive mixed micelles that contain two different polymeric surfactants. The exceptional control of these catalytic systems provides the opportunity to design the structure, function and assembly of the resultant biodegradable polymers and assemblies.
Abstract: Human activities such as fossil fuel combustion and deforestation emit increasing amounts of CO$_2$ into the atmosphere. Eventually, approximately half of this CO$_2$ will end up dissolved in the oceans, which will lower the pH of seawater. Increasingly acidic ocean waters pose a threat to organisms that precipitate calcium carbonate shells or skeletons. Recent studies indicate that deep ocean organisms are likely to be particularly sensitive to this changing pH. Deep-sea bamboo corals, which can live for hundreds of years, grow by adding sub-annual to annual bands of calcium carbonate. Thus, these organisms can potentially provide a high-resolution record of changing environmental conditions at depth. We examined uranium/calcium ratios in bamboo corals from the eastern Pacific for changes in the chemistry of their skeletons that might occur in response to variations in the pH of surrounding waters. Bamboo coral samples were analyzed using an inductively-coupled plasma-mass spectrometer to determine U/Ca ratios. Preliminary results indicate that U/Ca and pH in seawater may be inversely correlated, suggesting it may be possible for bamboo corals to provide insight into past ocean pH.
Abstract: The Chemical Dynamics Beamline at the Advanced Light Source (ALS), is a synchrotron user facility dedicated to perform investigations in chemical physics and physical chemistry using tunable vacuum ultraviolet (VUV) light for excitation or detection. Over the years, the beamline philosophy has evolved from performing state-of-the-art reaction dynamics studies towards a molecular level understanding of the processes that govern complicated phenomena in nature. Research towards alternative carbon neutral energy sources and mitigating global climate change are two themes of particular interest. Investigations in combustion dynamics, aerosol chemistry, nanoparticle physics, biomolecule energetics, imaging mass spectrometry, cosmo-chemistry, laser ablation and cluster studies, and elementary reaction kinetics are some of the projects being pursued at the beamline.

Ambient aerosols are known to play a significant role in a variety of atmospheric processes such as direct and indirect effects on radiative forcing. In this talk we will highlight our recent work using VUV mass spectrometry to study model hydrocarbon aerosol reactions with OH radicals. Results will be presented demonstrating the analytical and spectroscopic capabilities of VUV radiation to probe fragile bio-molecules in the gas phase generated via aerosol techniques, laser desorption, thermal vaporization and ion sputtering. The electronic structure of DNA base dimers and energetics of amino acid photoionization will be discussed. These studies pave the path to visualize chemical change on surfaces using imaging mass spectrometry, where VUV radiation allows for generation of chemical specificity at the molecular level coupled with spatial resolution down to the nano-scale.
Abstract: Gas-phase ion chemistry techniques for determining bond dissociation energies of neutral hydrocarbons of interest in combustion chemistry will be discussed. Guided ion beam tandem mass spectrometry is used to measure the cross sections for collision-induced dissociation of proton-bound dimers of two bases as a function of collision energy. Transition state theory is used to model the product branching fractions versus the available energy and to determine the energy differences between the two proton-transfer product channels. Applications include systems where multiple pathways and transition states from the reactant complex ions to various products must be considered. The experimental systems include recent work on carboxylic acids and polyynes.
Abstract: The heavy element group at Lawrence Livermore National Laboratory (LLNL) has had a long tradition of nuclear and radiochemistry dating back to the 1950’s. Some of the most exciting work has taken place in the last decade (in collaboration with the Flerov Laboratory of Nuclear Reactions in Dubna, Russia) with the discovery of five new elements - 113, 114, 115, 116, and 117. By pushing the boundaries of the periodic table, we can start to answer some of the most fundamental questions of nuclear science, such as the locations of the next “magic numbers” of protons and neutrons, and the possibility of an “Island of Stability” where nuclides would have lifetimes much longer than those currently observed in the heaviest elements. We have already seen evidence of extra-stability in the heaviest nuclides, which leads to half-lives that are long enough for us to perform chemistry on these isotopes one atom at a time. Work is already underway on developing a chemical system designed to isolate element 114. These experiments will allow nuclear chemists to accurately identify the chemical properties of element 114 and determine whether or not it truly behaves as a Group 14 element such as Sn or Pb. In this presentation, a brief history of the discovery of these new elements will be given as well as an introduction to the chemical experiments in progress.
Department Seminars in Chemistry
Fall, 2009

Madeline E. Rasche
Department of Chemistry/Biochemistry, California State University, Fullerton
Biosynthesis of Methanopterin, a Folate Analog in Methane-Producing Microorganisms
October 6, 11:00 AM
Classroom Building 170

Abstract: Methanogenic microorganisms play important roles in the environment by producing methane as both an energy source and a greenhouse gas. Biological methane production is dependent on tetrahydromethanopterin, a coenzyme which replaces tetrahydrofolate as a one-carbon carrier in methane-producing archaea. While eighteen reactions have been proposed in the pathway of methanopterin biosynthesis, only five of the corresponding enzymes have been identified. Our laboratory is using a combined biochemical, genetics, and comparative genomics approach to identify additional enzymes in the pathway and characterize the functions of these proteins in methanopterin biosynthesis. Chemical inhibitors of the first biosynthetic enzyme (RFAP synthase) have been synthesized and shown to decrease the production of methane by microorganisms from the rumen of cows, showing the potential for inhibitors of methanopterin biosynthesis to mitigate the production of methane as a greenhouse gas. An evolutionarily distinct group of microorganisms from the Bacteria domain appear to have acquired selected methanopterin biosynthesis genes from the methanogenic archaea. Molecular comparison of the bacterial and archaeal enzymes may provide insight into molecular events that may accompany the transfer of metabolic pathway genes between the archaea and bacteria domains.
Abstract: Cold cations of inorganic and organic molecules are produced in pulsed supersonic molecular beams by laser vaporization or pulsed discharge sources. These ions are mass-selected and studied with infrared photodissociation spectroscopy. Infrared spectra are compared to the predictions of theory (DFT and/or MP2) to elucidate the structures of these ions and, in the case of metal ions, their electronic states. Transition metal (Co, V, Nb) carbonyls are studied in the C-O stretching region and transition metal-water complexes are studied in the O-H stretching region. In both cases, the spectra reveal coordination numbers and ligand or solvent molecular vibrational shifts as a function of cluster size. Non-metal ions include protonated clusters of CO$_2$, CO, and N$_2$, in which the ligand vibrations and the proton stretching modes are measured, and a variety of carbocations ($\text{C}_2\text{H}_3^+$, $\text{C}_3\text{H}_5^+$, $\text{C}_3\text{H}_3^+$, protonated benzene, protonated naphthalene). The carbocation species exhibit more than one isomer, allowing investigation of the multiple minima on their potential surfaces. Protonated benzene and protonated naphthalene have spectral lines relevant for the Unassigned Infrared Bands seen in interstellar gas clouds.
Abstract: Catalysts interact with chemical reagents to control the pathway of a reaction, making the reaction more efficient and selective. Chiral catalysts are particularly important because they interact with chemical reagents in such a way that only one three-dimensional shape of a molecule (i.e. one stereoisomer) is produced. We are interested in the design of new chiral catalysts and new synthetic methods based on the unique properties of silicon. We have synthesized a series of silicon-based small molecule catalysts and evaluated their utility for asymmetric carbon-carbon bond-forming reactions, where we have observed excellent enantioselectivity (up to 99% ee). Our research uses synthetic, mechanistic and computational studies to systematically evaluate the properties of these silicon-based catalysts.
Abstract: Tandem mass spectrometry has been the method of choice for identifying small molecules, especially those present in trace quantities in complex mixtures, and is routinely used for protein identification and locating posttranslational modifications. Bond connectivity can be established based on fragmentation patterns but new methods for ion formation and activation can preserve weakly bound complexes making it possible to obtain detailed information about noncovalent interactions between ions, solvent and biomolecules, including macromolecular complexes of proteins and other biopolymers. New experiments on solvated ions and protein-protein complexes shed light into the role of solvent on molecular structure and reactivity as well as ion solvation. Electrochemical experiments done on gaseous ions using a novel nanocalorimetry method can be directly related to electrochemical reduction potentials in solution thereby making it possible to establish an absolute electrochemical redox scale. Infrared spectroscopy experiments on hydrated ions provide new information about solvent shell structures and how ions influence water structure. From these experiments, competitive interactions between ions, biomolecules and solvent are investigated and provide new insights into condensed-phase phenomenon.
Abstract: Despite the fact that an estimated 2% of the human genome codes for proteases, only a small fraction of these enzymes have well-characterized functions. An even smaller number have been targeted for therapeutic intervention. Characterization of proteolytic enzymes and their endogenous substrates presents a formidable challenge in the context of biological systems. Several recently developed techniques representing crucial advances toward identification of proteases and their natural substrates have improved the chances for defining the role of ‘orphan’ proteases with unknown function. One advance toward increasing the throughput of substrate-specificity determination has been the development of our positional scanning synthetic combinatorial libraries. To date, substrate libraries are the fastest method for determining the specificity of an enzyme and have proven effective in identifying substrates of highly selective proteases. With the development of positional scanning libraries, the time required to obtain protease specificity information has been reduced significantly and the role of several proteolytic enzymes have been determined. The recent advances in substrate identification highlight candidate substrates that must ultimately be validated in an actual biological setting. A method that we have been developing to assist in the validation process is the use of antibodies as inhibitors of protease function. The high affinity and specificity offered by antibodies are particularly attractive because proteases have historically been difficult to selectively target using other approaches. Inhibitors of serine proteases identified using bacteriophage display of antibody fragments were found to be potent and highly selective. The molecular basis of three antibody inhibitors have been determined from crystal structures of the antibody/protease complexes. The different mechanisms employed by the antibody inhibitors clearly show that antibodies are adept at identifying and using unique approaches to protease inhibition. As demonstrated by these examples, the solutions that are uncovered are not simply mimics of known protease inhibitors. The discovery of new modes for protease inhibition suggests that the antibody scaffold provides an environment that allows for unique unpredictable positioning of inhibitory loops. This approach should be applicable for any protease, and should greatly improve our ability to specifically inhibit individual proteases to help selectively regulate their activity and determine their functional roles.
Abstract: Time dependent measurements of fluorescence from single molecules can reveal chemical dynamics, such as conformational fluctuations, that are not evident in measurements on ensembles of molecules because the actions of multiple molecules are not synchronized. As a result, studies with single molecules have become popular for probing the sequence of events in complex biochemical processes. Single molecule fluorescence spectroscopy involves relating changes in fluorescence properties of fluorophores to the dynamics of interest in a macromolecule. The fluorescence intensity, spectrum and lifetime can all serve as probes of the dynamics.

We have developed a time-resolved, multi-spectral, confocal microscope with single molecule sensitivity. This instrument records the wavelength, emission time relative to excitation, and absolute detection time (time-stamped) for each detected fluorescence photon so that correlations among all the fluorescence properties are maintained. From the record of detected photons, simultaneous, time-dependent fluorescence intensity, spectra and lifetimes can be extracted. The correlated measurement of multiple properties can provide a more complete picture of the dynamical processes that affect the fluorescence. This presentation will describe recent results using this apparatus. These results include studies of single fluorophores on small proteins, single-pair fluorescence resonance energy transfer (spFRET) studies on simple spacer molecules and fluorescence dynamics measurements on complexes of quantum dots with dye-labeled proteins.
Abstract: Heterogeneous metal catalysts are nanoparticles that carry out reactions at high reactant gas pressures or in the liquid phase. Instruments developed in Berkeley for molecular studies under these conditions are sum frequency generation vibrational spectroscopy, high pressure scanning tunneling microscopy and ambient pressure X-ray photoelectron spectroscopy. Model surfaces were used to study heterogeneous catalytic reactions that permitted to control and monitor the atomic surface structure, composition and reaction intermediates and simultaneously measure reaction rates and selectivities. This way, precise quantitative correlations could be obtained between catalytic reaction kinetics and the molecular factors that control reaction dynamics. Single crystal surfaces were used at first as model catalysts followed by the use of metal and bimetallic nanoparticles that were synthesized with precise size and shape using colloid techniques. Catalytic studies that produce a single molecule (ethylene hydrogenation, CO oxidation) were redirected to focus on reaction selectivity in multipath chemical processes. Reactions were found to induce restructuring of the metal surfaces and mobility of adsorbed molecules. Reaction selectivity and rates can be altered by changing the nanoparticle size in the 0.8 – 10 nm range and shape (surface structure). Transition metal catalysts that are nanosize achieve facile restructuring and rapid change in surface composition under reaction conditions as their low atom coordination permits rapid bond rearrangements. Exothermic surface reactions can cause the flow of hot electrons at oxide metal interfaces and the clustering of metal atoms at the interface, which dramatically increases the metal oxide interface area. Improvements of techniques for molecular studies of surfaces that provide better time resolution and spatial resolution will enhance our ability to study the dynamics of surfaces, which are key to both activity and selectivity during catalysis. The control of metal nanoparticle size and shape provides opportunities to achieve superior reaction selectivity. Combined studies of nanoparticle catalyst synthesis, characterization and reaction studies will accelerate developments of this important field of chemical sciences and chemical energy conversion.
Abstract: The description and understanding of molecular behavior at all levels is rooted in our understanding of the distributions of electrons and the pathways and energies of electron movement. The oxidation and reduction processes of enzymes in biology, the selective making and breaking of bonds in industrial catalysis, the transport of electrons in molecular wires, and all other chemical and material properties share a common basis in the fundamental principles of electron energies and electron movement. Many of these principles have been derived from or demonstrated by photoelectron spectroscopy, a technique that is often introduced in freshman chemistry texts. This technique, based on the Einstein Photoelectric Effect for which Einstein was awarded the Nobel Prize, is conceptually simple in measuring the ionization energies of molecules and materials, but is profound in providing the most direct experimental probe of electronic structure and bonding. Recent applications have been particularly exciting in opening up new frontiers. Examples will be presented from diverse areas of chemistry, ranging from molecular electronics to metalloenzymes. Emphasis will be given to the bioinspired catalysis of hydrogen production by organometallic molecules, contributing to the prospect of a clean and efficient hydrogen fuel based economy.
Abstract: The marine natural products program begun at UC Santa Cruz (UCSC) in the early 1970’s has a rich history and continued promise for future significant discoveries. To date, almost 900 molecular structures have been established by the UCSC group from the study of marine invertebrates, especially sponges and marine-derived fungi, and these continue to captivate the interests of research groups throughout the world. Using case examples I will amplify on: (1) new scaffolds being explored for anti-cancer therapeutic lead development, (2) the continuing challenges to obtain sponge-derived compounds seemingly biosynthesized by microbial associants, (3) the potential and challenges associated with mining complex mixtures obtained from culture of marine-derived fungi.