Probing Exciton States in Hybrid Perovskite Semiconductors
Nadine Bradbury
Mentors: Geoffrey Blake, Griffin Mead, and Xiaolin Xu

Hybrid Organic-Inorganic Perovskites are a new generation of photovoltaic semiconductors that do not use scarce metals. Study of the viability of these materials involves detailed understanding of the various states an electron may go through in the material. Exciton states are bound excited electronic states just below the conduction band where the electron is essentially orbiting the “hole,” or positive charge, left behind by the promotion of an electron to the conduction band. These exciton states guard the transition between free and lattice electron, but their dynamics and timescales are not yet well understood. Proper characterization of the electron lifetime in the material involves understanding the timescales, and vibrational dynamics of these loosely bound states. We report an optically pumped, time resolved terahertz spectrum of MAPbBr3, a well-studied hybrid perovskite. Transitions between exciton states are resonant in the far-IR, or terahertz region of the electromagnetic spectrum, an area that has been difficult to study until relatively recent advances in generation and detection of this light. Obtaining details of the internal exciton dynamics between hydrogen-atom like states of electron-hole pairs provides an important piece of information for the directed evolution of this promising family of materials.

Terahertz Spectroscopy of Lead Halide Perovskites
Miha Valencic
Mentors: Geoff Blake, Xiaolin Xu, and Griffin Mead

Lead halide perovskites have grown in prominence over the last ten years due to their high energy conversion efficiency and low cost to produce. However, despite this increase attention, the reasons for the high conversion efficiency is largely unknown and the optoelectronic properties of lead halide perovskites are not well known. We have created an experiment to study the charge carrier dynamics in the lead halide perovskites CH3NH3PbBr3 and CH3NH3PbI3 using terahertz pump-probe spectroscopy. The perovskites are excited both above and below the band gap with the terahertz light sources and the charge carrier dynamics are monitored on a femtosecond time-scale. With the data taken from these experiments we can gain a greater understanding of the optoelectronic properties of lead halide perovskites and thus create more efficient and cost-effective solar cells.

Enantioconvergent, Photoinduced Copper Catalyzed Cross Coupling of Alkyl Halides With Primary Amines
Joseph E. Schneider
Mentor: Gregory C. Fu

Progress was made on the development of an enantioconvergent method for the photoinduced, copper-catalyzed cross-coupling of primary amines with racemic alkyl iodides. Investigations have found that product with an enantiomeric excess (ee) above 30% could be obtained contingent on the presence of an ethereal directing group on the electrophile, a hindered P1 phosphazene base, a temperature of −30 °C, and catalytic copper(I) iodide and enantiopure BINOL. Further changes to the reaction parameters (e.g. ligand development, changes to the directing group, additive effects) will hopefully optimize this transformation and allow us access chiral amines with high enantiopurity.

A Biochemical Basis for mRNA Export Regulation by the Nuclear Pore Complex
Sarah Cai
Mentor: André Hoelz

The nuclear pore complex (NPC) is one of the largest and most complex protein assemblies in eukaryotic cells, and it facilitates and regulates the bidirectional transfer of molecules between the nucleus and the cytoplasm. One of the essential functions of the NPC is to directly regulate the export of mature mRNAs, but the mechanism is not well understood, especially in humans. Export of mRNA is completed at the cytoplasmic face of the NPC, where the ATPase activity of the DEAD-box helicase DDX19 is specifically activated by Gle1, Nup42, and Nup214. Dysfunction of the essential mRNA export factor Gle1 has been linked to several human diseases. We show that the thermostability of Gle1 is highly dependent on Nup42, and we find that disease-linked mutants of Gle1 show strongly altered thermostability. Analysis of DDX19 steady-state ATPase activity reveals a novel mode of activation
by Gle1 in humans that is independent of the small molecule inositol hexaphosphate (IP6) in contrast to in fungi. Together with structural data of the DDX19-activating complexes, these results provide a detailed biochemical description of mRNA export regulation by the NPC and a framework for understanding the molecular basis of human disease linked to Gle1.

**Increasing Incorporation of Non-Canonical Proline in Proinsulin**
Kristen Goodfriend

**Mentors: David Tirrell and Alex Chapman**

Non-canonical amino acids (ncAAs) are produced by modifying the side chains of standard amino acids. When incorporated into therapeutic proteins, ncAAs could allow researchers to exert a medicinal chemistry-like control over the protein's structure and function. Insulin, a well-known therapeutic protein used to treat diabetes, is a model case for the applications of ncAAs. Insulin contains one proline residue at position B28, which can be replaced with proline derivatives in a residue-specific manner. While this method of ncAA mutagenesis sometimes results in high incorporation of certain ncAAs onto the peptide chain simply using the biosynthetic machinery of the host cells, some ncAAs cannot be properly charged onto the tRNA by the natural tRNA synthetase, resulting in minimal or no incorporation of the desired amino acid derivative. To address this issue, we have mutated the prolyl-tRNA synthetase to alter the binding pocket with the goal of accommodating (3R)-hydroxy-L-proline and (4S)-carboxy-L-proline. We have determined the qualitative extent of proinsulin expression and ncAA incorporation using gel electrophoresis. While we have observed no significant incorporation of (4S)-carboxy-L-proline using the mutated prolyl-tRNA synthetases, we are continuing to explore how these mutated synthetases affect the incorporation of other proline derivatives, including (3R)-hydroxy-L-proline.

**Genetically Encodable Sonomechanical Actuator for Controlling Gene Expression**
Aris Taychameekiatchai

**Mentors: Mikhail G. Shapiro and George J. Lu**

Being able to spatiotemporally control specific gene expression could have profound implications from basic research to the development of next-generation therapeutic methods. The objective of this project is to develop a genetically encodable method to non-invasively control gene expression in deep tissues. We chose gas vesicles as the actuator protein and focused ultrasound as the form of physical energy for control. Focused ultrasound can deliver a small localized pulse of energy to collapse gas vesicles exposing a hydrophobic surface, which we demonstrated using the fluorescent dye 8-anilino-1-naphthalenesulfonic acid (ANS). We hypothesize that the hydrophobic surfaces of the collapsed gas vesicles will mimic the exposed hydrophobic amino acids of an unfolded protein and trigger a signal cascade. We use qPCR and a fluorescence reporter assay to profile the resulting upregulation of genes in E. coli, and initially we are focusing on genes in the sigma 32 heat shock pathway and chaperone proteins.

**Engineering a Tet-On Responsive CRE/Lox Gene Switch**
Brian Lue

**Mentors: Mikhail Shapiro and Jerzy Szablowski**

There are numerous potential applications for an irreversibly activated gene circuit switch, ranging from the production of pharmaceutics and biofuels to the development of novel cancer therapeutic methods. One method of achieving a gene switch is accomplished via recombination. However, current systems are plagued by issues of gene leakiness, cytotoxicity, and inefficiency due to the requirement of multiple vectors. Thus, we are currently developing a Tet-On responsive CRE-Lox gene switch that minimizes leakiness and cytotoxicity while maximizing efficiency by utilizing a two AAV vector system. We have determined two unique methods of floxing a gene so that it will only be expressed when in the presence of CRE: lox-stop-lox (LSL) and double-inverted lox (DIO), and are currently in the process of cloning these vectors. *In vitro* experiments in mammalian cells with the Tet-On responsive CRE system also suggests that leakiness is a concern, so we are optimizing the system to reduce the background and enhance the signal.

**Engineering Acoustic Biomolecules as Dynamic Molecular Sensors for Ultrasound**
Teresa Anh Tran

**Mentors: Mikhail Shapiro and Anupama Lakshmanan**

Ultrasound is one of the most widely used biomedical imaging technologies, but has limited ability to image dynamic molecular and cellular processes due to the lack of suitable nanoscale contrast agents. Gas Vesicles (GVs), hollow protein nanostructures naturally occurring in several types of bacteria, have emerged a new class of genetically-encodable, nanoscale contrast agents for ultrasound. The genetic encodability of GVs provides a unique platform for engineering their mechanical, acoustic, surface and targeting properties at the level of their constituent proteins. In this study, we show that rationally designed genetic modifications to the key GV shell protein i.e. Gas vesicle protein C (GvpC), can be used to engineer GVs that respond to changes in concentration of
a physiologically important analyte, such as calcium. The genetically modified GvpC proteins can potentially undergo reversible conformational changes in the presence of the target, thereby altering the mechanical and acoustic properties of these engineered GVs and enabling them to act as dynamic acoustic sensors of physiologically relevant molecules.

**Plasma-Etched Nanoporous Graphene for Reverse Osmosis Desalinization**

Rebecca Mikofsky  
*Mentors: Konstantinos P. Giapis and Ben Kanevsky*

Nanoporous graphene is a valuable membrane for reverse osmosis desalinization, due to its increased theoretical performance over current polymer membranes. Graphene is a single layer of carbon atoms and nanoporous graphene (graphene with carbons knocked out) has properties of high permeability, tensile strength, and hydrophobicity. This allows water to pass through it well while salt is rejected. Chemical vapor deposition is used to grow the graphene on copper foil at 1000°C in the presence of hydrogen and methane gasses. The nanopores are introduced via plasma bombardment, then analyzed through Raman spectroscopy which depicts the defects of graphene. Helium plasma destroyed the samples within six seconds, so pretreatment cleaning time was increased and the gas was switched to argon, which is more capable of removing contaminants from the chamber. Argon plasma destroyed all the graphene within 40 seconds, allowing for more control. This increased accuracy allowed for samples of the same time to have more consistent defects. Further research can be done testing the membranes within a micro-fluidic setup in order to test salt rejection.

**Characterizing a Soft X-Ray Charger**

Jennifer Wu  
*Mentors: Richard Flagan and Changhyuk Kim*

The atmospheric aerosol is a suspension of small particles distributed over a wide range of sizes. The impact of those particles on the environment and human health is a strong function of the particle size distribution, which is measured by differential mobility analysis. The inference of particle size distributions from differential mobility analyzer (DMA) data requires knowledge of the charge distribution on the particles being measured. To obtain a known charge distribution, the particles pass through a bipolar diffusion charger in which they are exposed to an electrically neutral cloud of positive and negative ions produced by radioactive decay, soft X-rays, or other sources, and ultimately attain a steady-state charge distribution. We aim to characterize a soft X-ray charger, previously built by the Flagan group, by finding the fraction of positively charged particles over a range of particle sizes with diameters smaller than about 10 nm. To find these charge fractions, particles were generated by a hot wire source, charged by the soft X-ray charger, then passed through a nano-radial differential mobility analyzer (nRDMA) to separate the positively charged particles from the uncharged ones. Particle counts were measured upstream and downstream of the nRDMA to determine the charge fraction.

**Directed Evolution of an Iron-Containing Biocatalyst for C–H Amination**

Emily Miaou  
*Mentors: Frances Arnold and Ruijie (Kelly) Zhang*

All organic molecules contain a myriad of C-H bonds, which are typically considered to be chemically inert. Development of catalytic methods to reliably and selectively transform C-H bonds will transform the way chemical synthesis is performed. Existing methods for C-H bond functionalization suffer from several limitations, including their reliance on catalysts that are commonly complexes of precious metals with complex ligands. Furthermore, developing methods that achieve high stereocontrol in intermolecular transformations, which offer the greatest potential for streamlining synthesis, has been particularly challenging. This project seeks to develop hemoprotein catalysts for selective C-H functionalization, contributing to goals for conducting sustainable chemical production. Given that amines are found in many biologically active compounds and are highly versatile intermediates, they are considered extremely valuable products and targets for catalysis. Previous work in the Arnold lab has demonstrated that hemoproteins are competent catalysts for performing enantioselective intermolecular C-H amination using tosyl azide as the nitrene precursor. Given this finding, we hypothesize that hemoprotein-catalyzed intermolecular C-H amination chemistry can be extended to other nitrene precursors. In this project we design non-azide nitrene precursors and use directed evolution to create variants of hemoproteins capable of performing catalysis with these substrates. Ultimately, we aim to expand the scope of non-natural biocatalytic C-H amination chemistry.